8-2020

Automating and Analyzing Whole-Farm Carbon Models

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AUTOMATING AND ANALYZING WHOLE-FARM CARBON MODELS

by

Aditi Maheshwari

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Computer Science

Approved:

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UTAH STATE UNIVERSITY
Logan, Utah

2020

ABSTRACT

Automating and Analyzing Whole-Farm Carbon Models

by

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Utah State University, 2020

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Department: Computer Science

The goal of this research is to learn about whole farm carbon models. A whole farm carbon model estimates the emissions of greenhouse gasses (GHGs) based on information for a farm. We analyzed two models, HOLOS whole-farm and COMET-Farm, by running the models on random inputs and building classifiers from the runs. HOLOS estimates GHG emissions for a particular year based on crop and animal agriculture input, while COMET-farm adds past and future farm management practices. Users of the models must manually enter farm data through a graphical user interface (GUI), which is a good method for a single farm, but makes it infeasible to calculate GHG emissions over hundreds to thousands of farms. So we automated the interface and generated random farm scenarios within ranges given by experts. We scraped the estimated carbon footprint from thousands of runs of the models and used several Regression algorithms to build predictive models that have high accuracy. By reverse engineering the whole-farm carbon models we were able to determine which farm management practices in each whole farm carbon model have the biggest impact on GHG emissions. This can help farmers and rural planners change farm management practices to decrease GHG emissions.

(114 pages)

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The goal of this research is to learn about whole farm carbon models. A whole farm carbon model estimates the emissions of greenhouse gasses (GHGs) based on information for a farm. We analyzed two models, HOLOS whole-farm and COMET-Farm, by running the models on random inputs and building classifiers from the runs. HOLOS estimates GHG emissions for a particular year based on crop and animal agriculture input, while COMET-farm adds past and future farm management practices. Users of the models must manually enter farm data through a graphical user interface (GUI), which is a good method for a single farm, but makes it infeasible to calculate GHG emissions over hundreds to thousands of farms. So we automated the interface and generated random farm scenarios within ranges given by experts. We scraped the estimated carbon footprint from thousands of runs of the models and used several Regression algorithms to build predictive models that have high accuracy. By reverse engineering the whole-farm carbon models we were able to determine which farm management practices in each whole farm carbon model have the biggest impact on GHG emissions. This can help farmers and rural planners change farm management practices to decrease GHG emissions.

To my family, for their everlasting love and support.

ACKNOWLEDGMENTS

I would like to express my sincerest gratitude to Dr. Curtis Dyreson for his immense help and patience. I am extremely thankful to him for the detailed explanations and answers to all my questions, even the most trivial ones. This thesis truly would have not been possible without his unswerving support and advice.

I would also like to thank Dr. Jennifer Reeve and Anthony Whaley from agriculture department for their continuous help.I also want to extend my thanks to Dr. Dan Watson and Dr. John Edwards for being part of my committee.

Aditi Maheshwari

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CHAPTER 1

Introduction

This research is part of a larger project to better understand the potential preservation of agricultural land in Utah, specifically along the Wasatch Front. The fastest growing crop in Utah is houses. But unlike other crops, once houses are planted the land is no longer suitable for agriculture. Historic orchards, pastures, and farms are being converted to housing at a rate that, if unchecked, will lead to the loss of almost all agricultural land in some counties in the next few decades. While many forces are driving the loss of agricultural land, surveys of Utahans show that a majority of residents favor preserving agriculture. The history and culture of Utah is tightly connected to the land. Preservation of agricultural land has even landed on the ballot in many counties. An emerging trend in studying land use is to consider not just the market value of the land but also its *ecosystem services*, which include tourism, green space potential, historic and cultural valuations, potential for wildlife, water use, and impact on climate change.

This thesis focuses on better understanding how managing agricultural land impacts *climate change* as an ecosystem service. The concentration of greenhouse gases (GHG) has become a global problem. Because of the increase in carbon dioxide and other greenhouse gasses in the atmosphere, the Earth's atmosphere is trapping more heat. This warming is having undesirable effects on environments, economies, and livelihoods [3]. Scientists have projected many effects of climate change, such as rising sea levels and alarming weather patterns [3]. Climate change will impact biodiversity, food production, and the settlement and well-being of humans.

Farms contribute to the rapid increase of GHGs in the atmosphere [2]. As shown in Figure 1.1 carbon dioxide contributes the largest amount of GHG, primarily through the burning of fossil fuels, solid wastes and other biological material [2]. Agriculture, industrial activities and solid waste emit nitrous oxide. Around 10% of GHG comes from agriculture

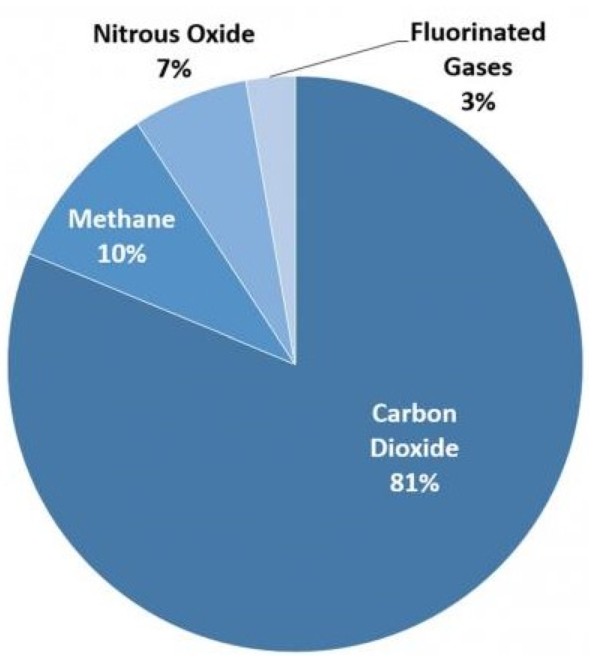


Fig. 1.1: Overview of Greenhouse gases in 2018 [2]

activities as shown in Figure 1.2. Livestock, agricultural soils, and crop production produces GHG [2].

There are several models for predicting the amount of GHG produced by a farm. We will refer to these models as *whole-farm applications*. A whole-farm application takes as input information about a farm, such as soil type, crops grown, and management practices, and estimates the amount of GHG the farm produces in a year. Running a whole-farm application requires a lot of manual input. The inputs are entered through a graphical user interface and require a user to select farm conditions from a tabbed set of drop down menus and other widgets. Once all the information about the farm is entered, a "run" button can be selected to produce an estimate.

There are three challenges to integrating whole-farm applications into an ecosystems services model. The first challenge is *automation*. For our purposes, it is necessary to model thousands of farms over thousands of different planning scenarios. For example, suppose that a planner wants to reduce the GHG emissions from farms in Utah county by 10% over a five year period. To measure how a farm could change over time a user would have to enter the information about a farm and then permute the management practices of that farm (e.g., reduce the livestock or change from growing alfalfa to quinoa) to determine by how much GHG emissions could be reduced. But Utah county has thousands of farms. So just this one planning scenario would involve many man-months of labor. A key challenge in using these models for our project is how to *automate* running the models.

The second challenge is *analyzing* the whole farm applications. We need to determine which management practices have the biggest impact on GHG emissions. A whole-farm application is a black box, we are not able to look inside and see what factors have the biggest impact on GHG. For example, if the goal is to reduce GHGs by 10% then should we change tillage practices, crops, or livestock practices? We need to better understand the models and how they work.

The third challenge is suitability. We need to figure out which model is best for the Wasatch Front. There are several whole-farm applications. Which model should we use, that is, which makes the best estimates for Utah's soils and agriculture?

The two most widely-used whole farm applications are COMET-Farm [4] and HOLOS [1]. HOLOS whole-farm application takes input for Crop production and animal agriculture for a particular year and generates a report of GHG emission. COMET-Farm takes as input past, present and future scenarios for crop and animal agriculture and produces a report with change in GHG from past and future scenarios. We chose to use Selenium to automate running COMET-Farm and WinAppDriver to run HOLOS as we discuss further in Chapter 3.

After automation we collected data from the applications. We randomly generated input (within ranges given to us by domain experts) and ran the whole-farm applications on the generated data. Running the automation scripts took approximately two months to collect the data for HOLOS. It took one month to collect data for COMET-Farm. We generated 5000 runs for COMET-Farm and 3000 runs for HOLOS.

The next step was to mine the generated data. We chose to use RapidMiner [5]. For a given data set, RapidMiner simultaneously runs several model building techniques: [list

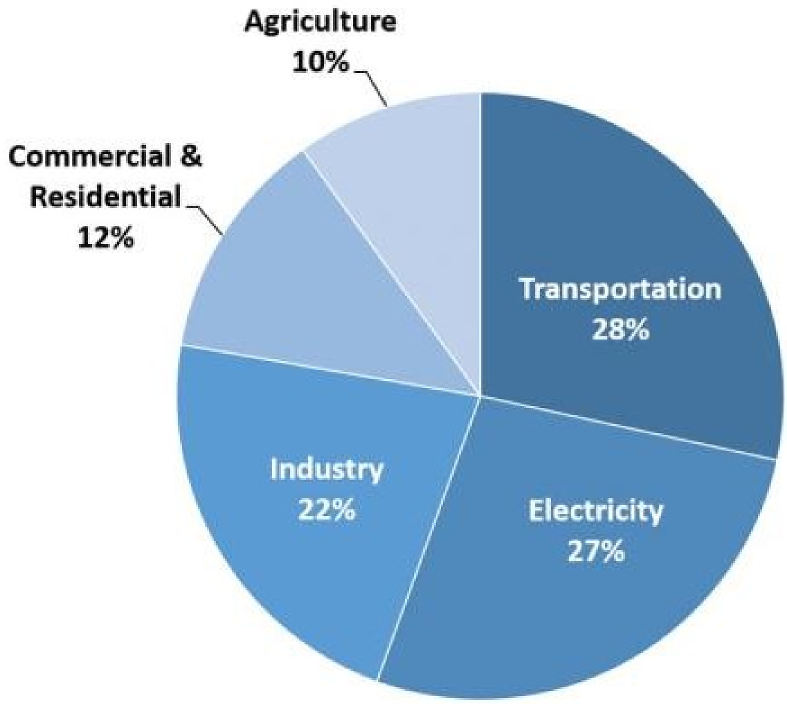


Fig. 1.2: Greenhouse gases emission from Economic Sector in 2018 [2]

techniques here], which allows a user to select the best technique for the data. We trained on 70% of the data and tested on the remaining 30%. RapidMiner helped us to understand which attributes had the biggest impact as described in Chapter **??**. We trained HOLOS on animal and crop production data together. For COMET-Farm data we used animal and crop data separately to train the model and determine attributes that have the biggest impact on GHG emissions.

This research yielded three results. First, by automating whole-farm applications it has made it very easy to collect data. This automation can be used in future if there is any change in ranges for inputs. It can also be used to generate an carbon footprint GIS layer for use in planning applications. Second, by knowing how different management techniques impact GHG emissions, we can rank the different practices and choose best practices. Third, we analyze differences between HOLOS and COMET-Farm, and potentially build a hybrid model that combines HOLOS and COMET-Farm.

There were four technical challenges in this research. The first challenge was choosing which whole-farm applications should be used since there are more than just HOLOS and COMET-Farm. The second challenge was to automate running the applications. They have interfaces designed for analyzing a single farm. We need to estimate carbon footprints for thousands to hundreds of thousands of farms. The third challenge was how to randomly generate "good" farm scenarios, as some combinations are not feasible. The fourth challenge was how to perform attribute selection on the collected data and decide which method is best for this research.

This thesis consist of five chapters. The first chapter introduces the research. The second chapter describes HOLOS and COMET-Farm. The third chapter is about how we automated the applications. The data mining of the applications is given in the fourth chapter. The final chapter gives conclusions and describes future work.

CHAPTER 2

Whole-farm Applications

This chapter describes, at an abstract level, the applications we used for ecosystems services modeling. There are several models for estimating the GHG emissions of a farm. By experimenting with the different models, we chose two for our project. An application we evaluated but chose not to is the well-known Luci Carbon model [6]. Luci is a framework used with ArcMap. Luci takes information about the topography, land cover, and soil type, but does not consider crop production and animal agriculture. We also evaluated the Invest carbon model [7]. Invest estimates the amount of carbon stored in the landscape and the amount of carbon sequestered over time. Input for this model is Land use/Land cover maps to get the amount of carbon stored in that piece of land. But like Luci, Invest also lacks input for farm management. In contrast, HOLOS and COMET-farm are whole-farm applications. They take into account crop production and animal agriculture in estimating GHG emissions. We describe both models in more detail in the rest of this chapter.

2.1 HOLOS

HOLOS is a software program to model a whole farm and calculate its carbon footprint [1]. HOLOS aims to envisage and try different possible ways to reduce the emission of GHGs. HOLOS considers possible emissions-reducing options and predicts how those options impact whole-farm emissions. In general, formulas used in the HOLOS model

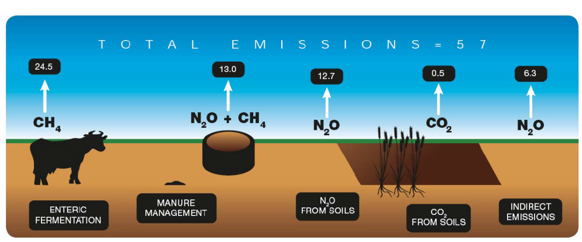


Fig. 2.1: Sources of GHG emission from a farm [1]

are focused on the principles of the Intergovernmental Panel on Climate Change but have been adapted for Canadian circumstances (HOLOS was developed in Canada for Canadian soils) [1]. HOLOS allows the user to input not only information about crops but also about animal agriculture. Table 2.1 shows the input attributes for HOLOS.

Farm Operation	**User Input Required**	**Defaults Provided**	**Emission Calculated**
Crops/Grassland /land use change	Area of annual crops & fallow Area of perennial crop Area of grassland Tillage System Area of irrigation Herbicide usage	Fertilizer inputs Crop yields Soil type and texture	Soil N20 Soil Carbon Storage or Emission Energy CO2
Beef Cow-calf	# Cows Types of grazing area Pasture and feed quality Feed additive in diet Spring or fall calving Year round grazing or winter feeding Calves sold or kept for back grounding # months kept Manure handling system	Calf crop rate # bulls	Entire CH4 Manure CH4 Manure N20 Energy CO2
Beef feedlot	Type of feedlot Feedlot capacity and/or # months filled Barn housing usage Ration mix Feed additive in diet % steers in lot Feed gain ratio Average daily gain Manure handling system	Initial and Final weights	Entire CH4 Manure CH4 Manure N20 Energy CO2
Beef stocker	# cattle # months grazed Pasture quality Feed additive in diet % steers in herd Average daily gain	Initial and Final weights	Entire CH4 Manure CH4 Manure N20

Dairy	# cows # months grazed Feed additive in diet Pasture usage and length of time used Manure handling system Season of manure application	# replacement heifers # bulls # calves Length of dry period total digestible nutrients or net energy for lactation and protein contents in diet	Entire CH4 Manure CH4 Manure N20 Energy CO2

Table 2.1: HOLOS Input [1]

HOLOS estimates carbon dioxide, nitrous oxide and methane emissions from enteric fermentation and manure management, cropping systems and energy use. HOLOS takes as input common farm operations as summarized in Table 2.1. Carbon storage and loss from lineal tree plantings and changes in land use and management are estimated leading to a whole-farm GHG estimate. The estimate is based on a yearly time-step and results are provided as reports or comparative charts.

2.2 COMET-Farm

COMET-Farm is a whole-farm and ranch carbon and GHG accounting system [4]. COMET-Farm calculates the carbon footprint of the farm using past and future management practices. This tool allows you to test different options to reduce GHG emissions and provides general guidance to change the management practices that are likely to reduce GHG emissions for the same scenario. It takes in account the data from 1980 to 2029. COMET-Farm uses detailed spatially-explicit data of climate and soil conditions for a particular location. COMET-Farm allows a user to enter field and livestock information to accurately estimate emissions. Crop or pasture management practices starting from at least 2000 can also be input so users have the ability to add historic data if available and include cropping sequence and approximate planting and harvest date; type of grazing system, type of tillage system; rate, timing, type and application method for fertilizer and manure applications; irrigation method and application rate, and residue management. The livestock module allows users to enter details about the size and composition of herds (i.e., species, sex and age ratios) and the manure management system. Information on capital equipment and on-farm energy production is needed for COMET-Farm's energy module. The attributes of COMET-Farm are summarized in Table 2.2.

Farm Operation	**User Input Required**	**Defaults Provided**	**Emission Calculated**
Annual Crop/ Hay/ Grass or Seasonal Crop	Type of crop Planting Date Harvest Date Yield Grazing start date Grazing end date Grazing rest period Implement date Implement pass fertilizer date Fertilizer type Fertilizer total N applied Manure Date Manure Type Manure amount applied Irrigation date Inches per application	% straw Soil Total fertilizer applied Moisture % Total nitrogen % Ammonium nitrogen %	Soil N20 Carbon Storage & emission Energy CO2
	Liming date Liming type Burning		
Orchard/ Vineyard crop	Type of crop Prune Renew Implement date Implement pass fertilizer date Fertilizer type Fertilizer total N applied Manure Date Manure Type Manure amount applied Irrigation date Inches per application Liming date Liming type Burning	Total fertilizer applied Moisture % Total nitrogen % Ammonium nitrogen %	Soil N20 Carbon Storage & emission Energy CO2

Beef Feedlot	diet on Feedlot # Beef heifers # Beef Steers Primary breed Average daily weight gain heifers Average daily weight gain steers Average live weight gain heifers Average live weight gain steers Type of feed Feed % Feeding situation Solid/liquid separator Separator type Solid treatment method Liquid treatment method Manure system	Typical mature weight % of solid removed Manure produced per day % nitrogen content in manure	Entire CH4 Manure CH4 Manure N20 Energy CO2
Beef Steer or Heifers stockers	unique herds # Beef steers or heifers Average body weight Average daily weight gain Average mature weight Hours work each day Type of feed Feed % Feeding situation Solid/liquid separator Separator type Solid treatment method Liquid treatment method Manure system	% of solid removed Manure produced per day % nitrogen content in manure	Entire CH4 Manure CH4 Manure N20

Dairy Lactating Cow	# unique herds # Roofed facility # Dry Lot # Pasture Range Daily feed intake Average live body weight Days in milk Type of feed Feed % Housing type days manure in housing Feeding situation Solid/liquid separator Separator type Solid treatment method Liquid treatment method Manure system	% of solid removed Manure produced per day % nitrogen content in manure	Entire CH4 Manure CH4 Manure N20 Energy CO2

Table 2.2: COMET-Farm Input

To estimate total GHG emissions this tool uses knowledge on management practices together with spatially-explicit information on climate and soil conditions from USDA databases to run a series of models for each potential source of GHG emissions. For the Field Module, estimates are made using the DayCent dynamic model, which is the same model used in the official U.S. National Greenhouse Gas Inventory. Emissions in the Livestock Module are estimated using statistical models based on USDA and university research and are similar to models used in the U.S. National Inventory. Estimates in the Energy Module are based on the models used in the USDA/NRCS Energy Tool along with supplemental peer-reviewed research results.

CHAPTER 3

Automation

In this chapter we describe the how we automated HOLOS and COMET-Farm to collect data about how the applications work.

3.1 The Need to Automate Whole Farm Applications

There is a critical need to automate running whole-farm applications. Both HOLOS and COMET-Farm have only GUIs that require users to manually input farm parameters using text boxes, drop-down menus, and radio boxes. Neither program has a command-line interface. Each run is time-consuming, often a single run takes several minutes to enter all of the input. Since we need to run the applications for thousands of scenarios, manually inputting the scenarios is infeasible. Hence we had to automate running the applications. For HOLOS we used WinAppDriver [8] and for COMET-Farm, we used Selenium [9].

3.2 Automating HOLOS

HOLOS is a Windows desktop application. For its automation, we initially tried Python's pyWinAuto library. This library is suitable for automating a desktop application. But it is a very recent library, and its documentation is a work in progress. We ran into a problem in selecting menu items that we were unable to solve. So we switched to WinAppDriver [8], which is like Selenium but for desktop applications.

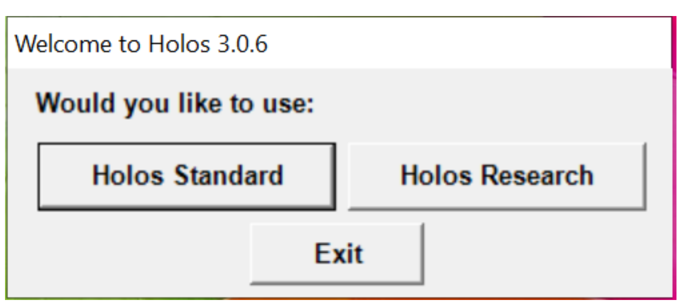


Fig. 3.1: HOLOS welcome Window

HOLOS has two modes of operation, Standard and Research, as shown in ‘ Figure 3.1. The standard mode is for general purpose use and has less detailed inputs, while the research mode requires input for all parameters. We used only the research mode. To create a data set we randomly choose values for each input within the ranges provided by experts for the software. The ranges are shown in Table 3.1. The ranges are based on real-world farms.

Variable	**Min Value**	**Max Value**	**Multiple Option**
Farm Name			Any Name
Farm year	1900	2050	
Eco district	358	1091	
Province			Alberta
Ecozone			Smiarid Pairies
Soil Texture			Fine Medium Coarse
Soil Type			Black/Gray Chernozem Brown Chhernozem Dark Chernozem Eastern Canada
Present Till Management Practice			No Till Reduce Intensive
Past Till Management Practice			No Till Reduce Intensive
LumC Max	-6071	6071	
k	0.0091	0.35	
Precipitation(mm)	0	1524	
Potential Evapotranspiration(mm)	0	1524	
F topography	0	100	
Soil N2O Breakdown(%)	0	100	
Average Temp C	-50	50	
RF Texture	0	1	
RF Tillage	0	1	
EF Eco (kg N2O-N/kgN)	0.0016	0.0017	
Leaching Fraction	0.05	0.3	
EF Leaching (kg N2O-N/kgN)	0.0075	0.0075	

Volatilization Fraction	0.1	0.1	
EF Volatilization (kg N2O-N/kgN)	0.01	0.01	
Global Warming Potential (CO2)	1	1	
Global Warming Potential (CH4)	28	28	
Global Warming Potential (N2O)	265	265	
Crop - Perennial			Hay - Grass Hay - Legume Hay - Mixed Hay and Forage Seed Other
Area (ha)	0.1	3	
Year Seeded	1910	2020	
Yield (kg DM/ha)	2242	13450	
Stand Length (yrs.)	1	10	
Irrigated			Yes or No
Herbicide N Fertilization Rate (kgN/ha)	 22	 169	Yes or No
P Fertilization Rate (kgP2O5/ha)	56	135	
Moisture Content (w/w)	0.02	0.75	
AGR N Concentration (kgN/kg)	0.005	0.018	
BGR N Concentration (kgN/kg)	0.007	0.015	
Yield Ratio	0.12	0.72	
AGR Ratio	0.08	0.6	
BGR Ratio	0.15	0.7	
Fuel Energy (GJ/ha)	0.34	2.83	
Herbicide Energy (GJ/ha)	0	0.23	
LumCMax	-6071	6071	
k	0.0091	0.35	
Beef Feedlot Finishers Group 1			
Ash Content (%)	8	8	
Bo	0.19	0.19	
CD Steer	1	1	

CD Heifer	0.8	0.8	
# Days	0	31	
# Heifers	1	1000	
Initial Heifer Weight (kg)	362	363	
Final Heifter Weight (kg)	817	817	
Heifer ADG (kg)	0.6	2.5	
# Steers	1	1000	
Initial Steer Weight (kg)	362	363	
Final Steer Weight (kg)	545	545	
Steer ADG (kg)	0.6	2.5	
Housing			Confined No Barn Housed In Barn Enclosed Pasture Open Range Custom
Diet			Barley Corn Custom
Diet Additive			None 2% Fat 4% Fat Custom
Manure System			Pasture Solid Storage Compost Intensive Compost Passive Custom

Table 3.1: HOLOS Input ranges provided by experts

To generate data, we wrote a script that executes HOLOS. To start the process a new file should have been created and an option to choose the measurement system will appear as shown in Figure 3.2 with options of metric and imperial. For this research we chose metric.

The first window is a farm information form shown in Figure 3.3. The basic information is Farm name, Farm Year, Province, Ecozone, Soil Type and texture. There are different

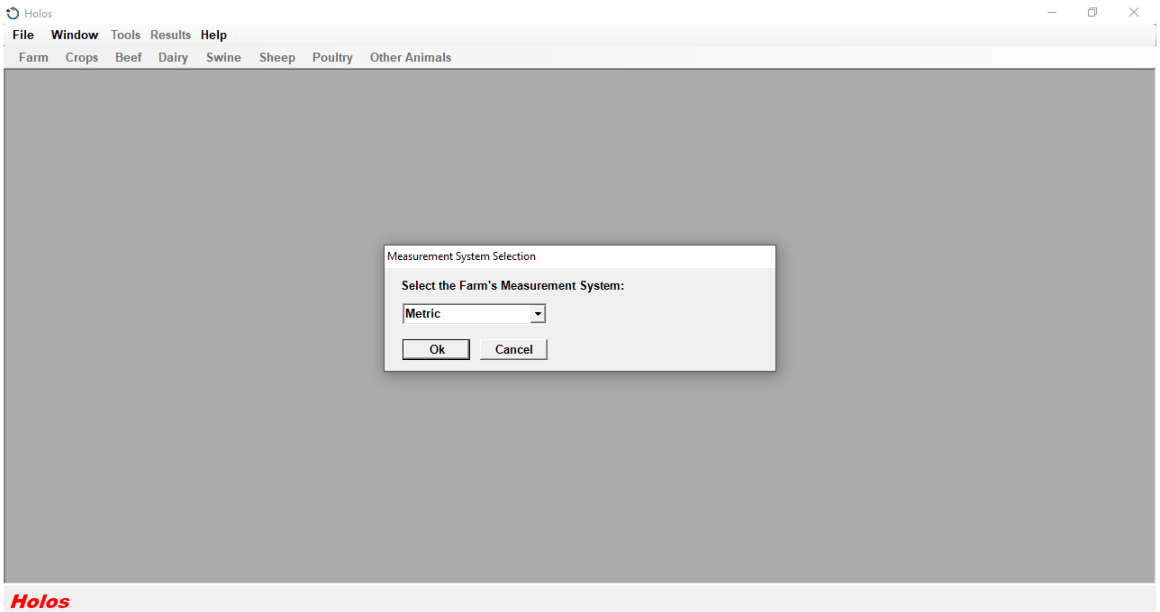


Fig. 3.2: HOLOS Measurement System

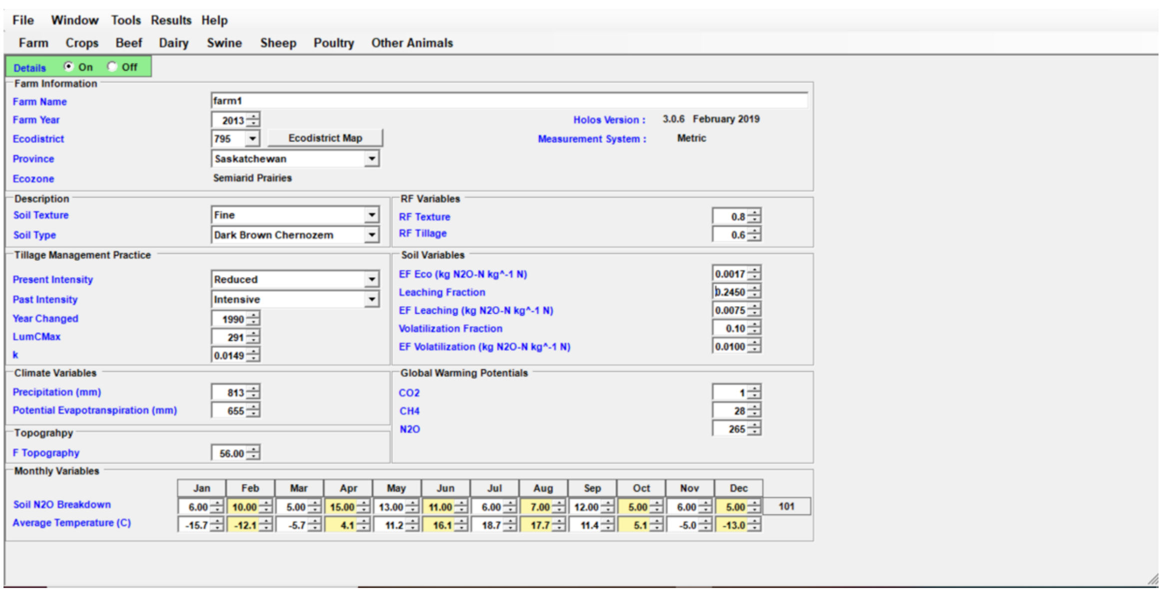


Fig. 3.3: HOLOS Farm Information Form

input widgets in this form, e.g., Combobox, select options, and input textbox. Some fields, such as Soil N20 breakdown, are populated by default using information from Farm year and Province. We faced a problem in clearing a Combobox as we were unable to clear it with the inbuilt clear() function of the window application driver. So we decided to use right-click select all and cut to clear the Combobox. Other than Combobox for everything else we just cleared the textbox and sent the keys using the send_keys() method.

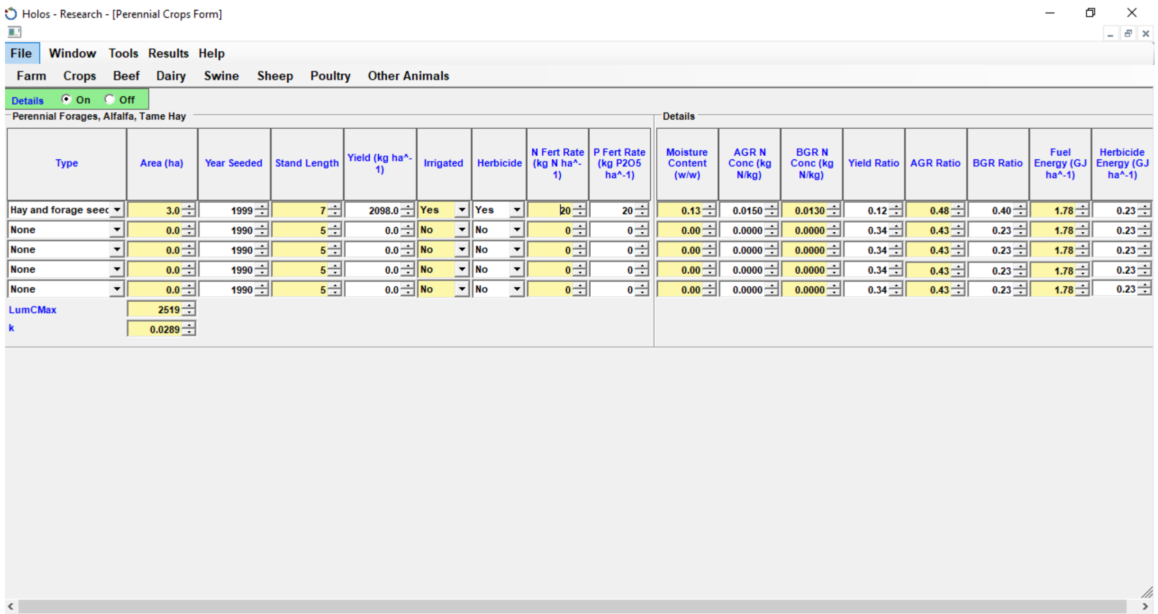


Fig. 3.4: HOLOS Perennial Crop Form

HOLOS has options to select the types of crop like Annual, Perennials, Fallow Areas, Grassland, and Tree planting. We worked with perennial crops for data collection. The Perennial Crop form has options to select up to five crops as shown in Figure 3.4. Crop-related information such as year seeded, strand length, area of the crop planted, irrigated or not, and also different ratios like yield ratio, AGR ratio, BGR ratio are put into the form. Year seeded seems like a minor input, but for GHG emissions in real-farms it has a huge impact. Some crops help seed carbon in the soil. For such crops, if the seeding is far in the past, then the soil's carbon bank potential is large and GHG emissions for current use will be reduced. The year seeded in some sense controls the size of the GHG bank. In our randomly generated scenarios we did not specifically control for year seeded, rather we allowed this to vary randomly (with uniform probability distribution).

For animal agriculture HOLOS provides a different set of options such as choosing the type of animal: Beef, Dairy , Swine, Sheep, Poultry, and Other Animals. For Wasatch front conditions we focused on Beef Feedlot. The Beef Feedlot form gathers information about

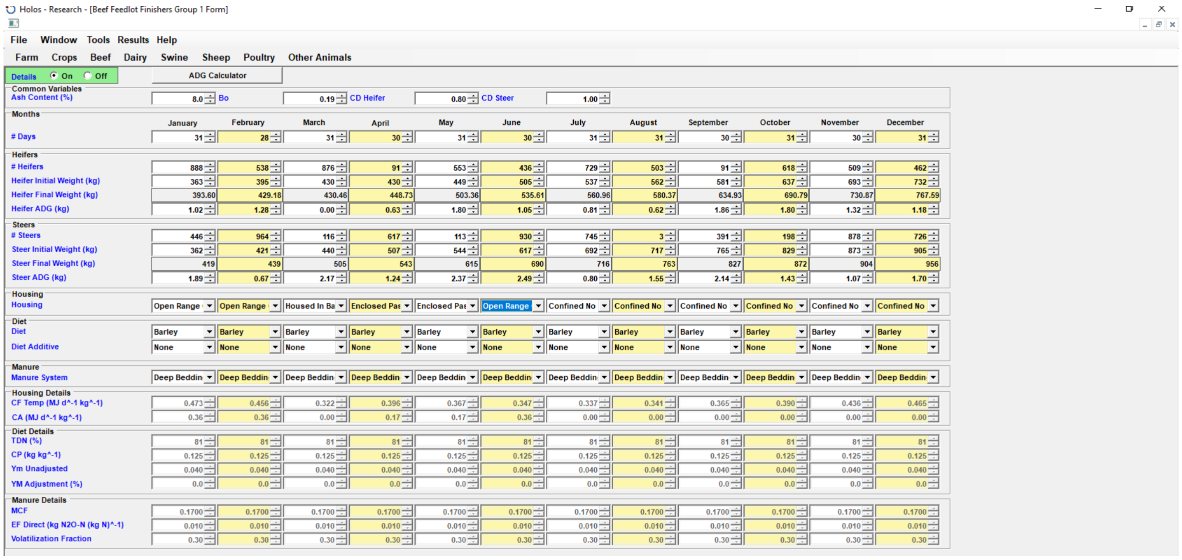


Fig. 3.5: HOLOS Beed Feedlot Form

the number of Heifers and steers, their initial weight, their daily weight gain and mature weight. Also information about housing, manure and diet. Housing, Diet and Manure have the option of accepting custom input.

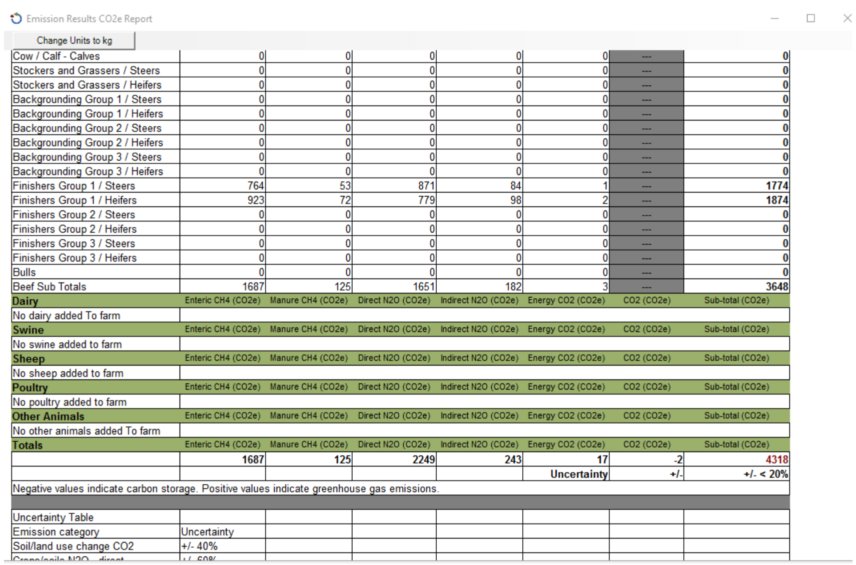


Fig. 3.6: HOLOS GHG Emission Result

After completing the perennial crop and beef feedlot forms the GHG report can be generated as shown in Figure 3.6. By exporting this report into an excel spreadsheet we can extract the GHG emission values. So each run is a row in the spreadsheet that relates inputs to outputs.

3.3 COMET-Farm Automation

COMET-Farm is a web application. We used Selenium to automate it [9]. COMET-Farm allows three kinds of crops, the kind of input varies depending on the crop. It also takes input for several types of animals. We assumed four different types of animals. Automation of this application was quite challenging because its input fields change for every option. It also has past, present and future inputs.

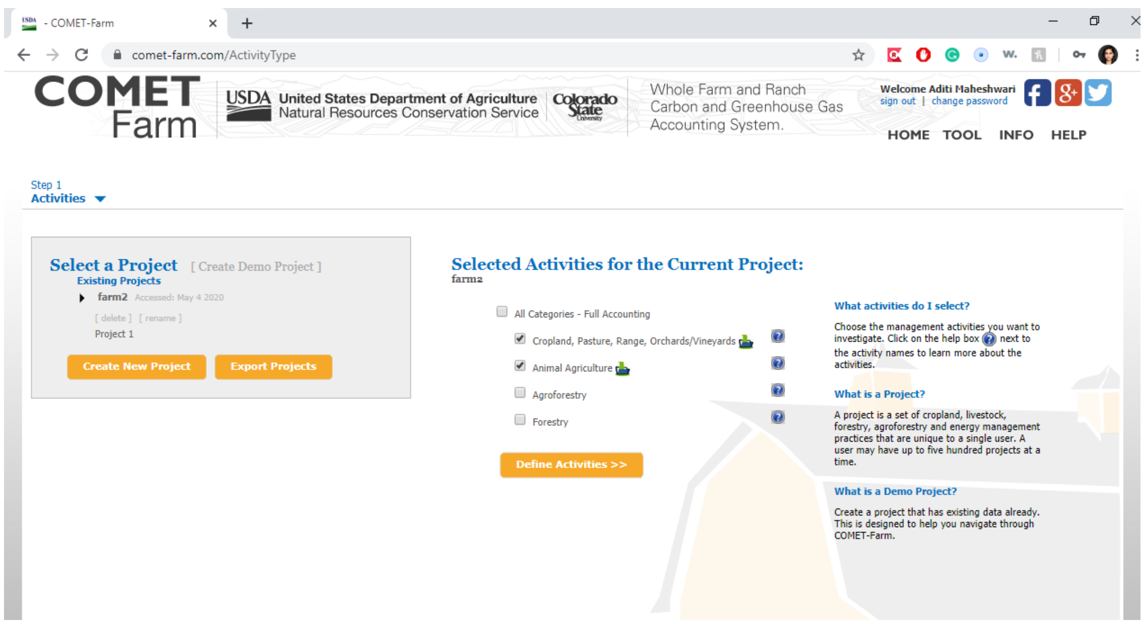


Fig. 3.7: COMET-Farm Management Activities Page

We started by loading COMET-Farm's web address in a chrome driver. COMET-Farm needs an id and password to enter into the application. We then entered data randomly chosen from the data ranges provided by specialist shown in Table 3.2. The data ranges are based on real-world scenarios.

COMET-Farm has modes for four types of management, which can be selected as shown in Figure 3.7. First is about agriculture, such as choosing among Cropland, Pasture, Range, Orchard/Vineyard. Second is the kind of animal agriculture practiced. Third is about agroforestry, and fourth is foresty. For this research we only worked with agriculture and animal agriculture.

Variable	**Sub-Variable**	**Options**
Step 1 - Activities	Selected Activities for the Current Project	Cropland, Pasture, Range, Orchards/Vineyards
Step 2 - Field Management	Parcel Locations	Orchard File Forage File
Historic Management	Pre-1980 Management	Irrigation (Pre-1980s) Livestock grazing Upland non-irrigated (Pre-1980s) Lowland non-irrigation (Pre-1980s)
	1980-2000 Management	annual crops in rotation continuous hay/pasture in rotation continuous hay annual crops in rotation continuous hay livestock grazing fallow-grain orchard or vineyard
	1980-2000 Tillage Intensity	No till Reduced tillage Intensive tillage
Baseline Management	Type of crop	Orchard/Vineyard Crop Annual crop/hay/grass Seasonal cover crop
	Crop Selection	For Orchard/Vineyard Crop : Cherries Grape-raisan Grape-table Grape-wine (>1950 GDD) Peaches and Nectarines Pistachio For Annual crop/hay/grass : Alfalfa Barley Corn Corn silage Grass Grass-legume mix Oats Rye Sorghum Spring wheat Winter wheat

		For Seasonal cover crop : Annual Rye - Legume - Radish Annual Rye - Legume Annual Rye Austrian Winter Pea Cereal Rye Clover Corn Forage Radish Millet Oilseed Radish Winter Grain - Other Sorghum Vetch
	Did you prune?	For Orchard/Vineyard Crop : Yes or No
	Did renew or clear your orchard/vineyard this year?	For Orchard/Vineyard Crop : Yes or No
	Planting Date	For Annual crop/hay/grass : 5/1 to 7/1 For Seasonal cover crop : 9/1 to 11/1
	Harvest date	For Annual crop/hay/grass : 7/1 to 11/1 For Seasonal cover crop : 4/1 to 6/1
	Harvest Straw	For Annual crop/hay/grass : 12 to 72 For Seasonal cover crop : 12 to 72
	Harvest Yield	For Annual crop/hay/grass : Alfalfa - 4.3 Tons/acre Barley - 93 bu/acre Corn - 24 tons/acre Corn silage - 24 tons/acre Grass - 138 bu/acre Grass-legume mix Oats - 154 bu/acre Rye - 154 bu/acre Sorghum - 54 bu/acre Spring wheat - 54 bu/acre Winter wheat - 54 bu/acre

	Grazing Start Date Grazing End date Rest Period	For Annual crop/hay/grass : 4/1 10/1 21
	Tillage, Implements and Planting	For Orchard/Vineyard Crop : Mow For Annual crop/hay/grass : No Tillage Mow Zero Soil Disturbance No implement passes For Seasonal cover crop : Intensive Tillage Reduced Tillage Mulch Tillage Ridge Tillage Strip Tillage No Tillage Crimp Broadcast Seed Aerial Seed

	Fertilizer Type	For Orchard/Vineyard or Seasonal or Annual crop: Ammonium Nitrate (34-0-0) Ammonium Nitrate Phosphate (23-23-0) Ammonium Nitrate Phosphate (27-14-0) Ammonium Phosphate Sulphate (16-20-0) Ammonium Polyphosphate Solution (10-34-0) Ammonium Sulphate (21-0-0) Ammonium Thiosulphate Solution(12-0-0) Anhydrous Ammonia (gas) (82-00-00) Calcium Ammonium Nitrate Calcium Nitrate Diammonium Phosphate (18-46-0) Element-N (N) Element-P (P) Mixed Blends Monoammonium Phosphate (11-55-00) Monoammonium Phosphate (12-51-00) Potassium Nitrate Urea (46-00-00) Urea Ammonium Nitrate (30-00-00) Urea Ammonium Phosphate (27-27-00) Urea Ammonium Phosphate (34-17-00)
	Fertilizer Date	For Orchard/Vineyard Crop : May 01 For Annual crop/hay/grass : Two weeks after planting date For Seasonal cover crop : Two weeks after planting date
	Fertilizer Total N Applied	For Orchard/Vineyard or Seasonal or Annual crop: 19 - 151
	Manure Type	For Orchard/Vineyard or Seasonal or Annual crop: Alfalfa Meal Beef Manure, Solid Beef Slurry Blood, Dried Bone Meal Chicken - Broiler (litter), Solid Chicken - Broiler Slurry Chicken - Layer Slurry

		Chicken Layer - Solid Compost or Composted Manure, Solid Dairy Manure, Solid Dairy Slurry Farmyard Manure, Solid Feather Meal, Solid Feather Meal Fish Emulsion Fish Scrap Guano Horse Manure, Solid Other Manure, Solid Sheep Manure, Solid Soybean Meal Swine Manure, Slurry Swine Manure, Solid
	Manure Date	For Orchard/Vineyard Crop : May 01 For Annual crop/hay/grass : Two weeks before Planting Date For Seasonal cover crop : Two weeks before Planting Date
	Manure Amount Applied	For Orchard/Vineyard or Seasonal or Annual crop: 5 - 25
	Irrigation Inches per application	For Orchard/Vineyard Crop : 1.8 - 2.25 For Annual crop/hay/grass : 2.5 For Seasonal cover crop : 1 - 2
	Irrigation date	For Orchard/Vineyard Crop : Once per week starting 5/1 - 11/1 For Annual crop/hay/grass : Once every 11 days starting 5/1 - 11/1 (starts from planting date) For Seasonal cover crop : Once per week 9/1 to 6/1. (starts from planting date)
	Liming	For Orchard/Vineyard or Seasonal or Annual crop: None
	Burning	For Orchard/Vineyard or Seasonal or Annual crop: No Burning

Step 3-Animal Agriculture	Units of measure	Metric
	Select Animal Types	Beef-heifer stockers Beef-steer stockers Stockers Feedlot cattle Dairy-lactating cows
	# unique herds	For Beef-steer and Beef-heifer Stockers: 1 For Dairy-lactating cows: 1
	# diets fed on feedlot	For Stockers Feedlot cattle: 1
	# Heifers	For Stockers Feedlot cattle and Beef-heifer Stockers : 1 - 500
	# Steers	For Stockers Feedlot cattle and Beef-steer Stockers: 1 - 500
	Aveage stockers body weight	For Beef-steer and Beef-heifer Stockers: 362
	Aveage stockers daily weight gain	For Beef-steer and Beef-heifer Stockers: 0.6 - 2.5
	Aveage stockers mature weight	For Beef-steer and Beef-heifer Stockers: 545
	Primary Breed	For Stockers Feedlot cattle: Angus Brahman Charolais Chianina Gelbvieh Hereford Limousin Main Anjou Pinzgauer Red Poll Sahiwal Simmental South Devon Tarentaise Other
	Average Daily weight gain	For Stockers Feedlot cattle: for Spring, Summer, Fall, Winter for both Heifers and Steers 0.6 - 2.5

	Average Live weight	For Stockers Feedlot cattle: from Jan - Dec for both Heifers and Steers 362 - 545
	Do you use ionophores	For Stockers Feedlot cattle: Yes or No
	Fat Content in the diet	For Stockers Feedlot cattle: 1% Supplemental Fat 2% Supplemental Fat Four or higher added fat content No supplemental fat added
	Grain Type in diet	For Stockers Feedlot cattle: Steam Flaked or High Moisture Unprocessed or Dry Rolled Barley rather than corn or sorghum
	Concentrate % in diet	For Stockers Feedlot cattle: More than 60% grain 45 to 60% grain Less than 45% grain
	# Roofed Facility	For Dairy-lactating cows: 1 - 500
	# Dry Lot	For Dairy-lactating cows: 1 - 500
	# Pasture Range	For Dairy-lactating cows: 1 - 500
	Average daily feed intake	For Dairy-lactating cows: 0
	Average live body weight	For Dairy-lactating cows: 362 - 545
	Average daily feed intake	For Dairy-lactating cows: 305
	Days in milk	For Dairy-lactating cows: 28.6
	Range of months for feed	For For Dairy-lactating cows and Beef-steer and Beef-heifer Stockers: Select Jan to Dec

	Types of Feed	For Dairy-lactating cows and Beef-steer and Beef-heifer Stockers: Alfalfa Birdsfoot Bromegrass Cheatgrass Elephant grass Grain Grass Meadow Oat Orchardgrass Prairie Rye Sanfoin Sorghum Sudangrass Vetch Wheat Wheatgrass
	Percentage of feed	For Dairy-lactating cows and Beef-steer and Beef-heifer Stockers: 100 %
	Percentage of feed	For Dairy-lactating cows and Beef-steer and Beef-heifer Stockers: 100 %
	Primary Feeding Situation	For Beef-steer and Beef-heifer Stockers: Stall Pasture Grazing large areas
	Housing Type	For Dairy-lactating cows: Pit Storage Bedded Pack Flushed or Scraped
	Pit Storage Type	For Dairy-lactating cows: Deep Shallow
	Pit Storage days in housing	For Dairy-lactating cows: 1 - 7
	Bedded Pack Type	For Dairy-lactating cows: Active Mix No Mix

	Bedded pack days in housing	For Dairy-lactating cows: 1 - 7
	Flushed or Scraped area of Barn	For Dairy-lactating cows: 0.4 - 2.8
	Use Solid/Liquid Separator	For Dairy-lactating cows and Beef-steer and Beef-heifer Stockers and feedlot cattle: Yes or No
	Storage Method	For Dairy-lactating cows and Beef-steer and Beef-heifer Stockers and feedlot cattle: Temporary stack and long-term stockpile Composting Aerobic lagoon Anaerobic digester with biogas utilization or methane capture Thermochemical Conversion (Pyrolysis, Incineration, Gasification) Constructed wetland Daily spread Deposited on Pasture/Range/Paddock Removed offsite Land applied
	Separator type	For Dairy-lactating cows and Beef-steer and Beef-heifer Stockers and feedlot cattle: Stationary inclined screen Vibrating screen Rotating screen Centrifuge Decanter centrifuge Roller press Pressure filter Other
	Solid Treatment Method	For Dairy-lactating cows and Beef-steer and Beef-heifer Stockers and feedlot cattle: Temporary stack and long-term stockpile Composting Thermochemical Conversion (Pyrolysis, Incineration, Gasification)

		Daily spread Deposited on Pasture/Range/Paddock Removed offsite Land applied
	Liquid Treatment Method	For Dairy-lactating cows and Beef-steer and Beef-heifer Stockers and feedlot cattle: Aerobic lagoon Anaerobic digester with biogas utilization or methane capture Thermochemical Conversion (Pyrolysis, Incineration, Gasification) Constructed wetland Daily spread Deposited on Pasture/Range/Paddock Removed offsite Land applied
	Solid Storage System Cover Type	For Dairy-lactating cows and Beef-steer and Beef-heifer Stockers and feedlot cattle: AUncovered solid Covered solid Uncovered semi-solid Covered semi-solid
	Solid Storage Is the manure stored for more or less than six months?	For Dairy-lactating cows and Beef-steer and Beef-heifer Stockers and feedlot cattle: Long term (more than six months) Short term (less than six months)
	Composting Method	For Dairy-lactating cows and Beef-steer and Beef-heifer Stockers and feedlot cattle: In Vessel Static Pile Intensive Windrow Passive Windrow
	Aerobic lagoon Total Volume	For Dairy-lactating cows and Beef-steer and Beef-heifer Stockers and feedlot cattle: 400 - 20,000

	Aerobic lagoon Is the system aerated naturally or by forced aeration?	For Dairy-lactating cows and Beef-steer and Beef-heifer Stockers and feedlot cattle: Natural Aeration Forced Aeration
	Anaerobic digester with biogas utilization or methane capture digestre Type	For Dairy-lactating cows and Beef-steer and Beef-heifer Stockers and feedlot cattle: Steel or lined concrete or fiberglass digesters with a gas holding system (egg shaped digesters) and monolithic construction. Up-flow anaerobic sludge blanket (UASB) type with floating gas holders and no external seal Unlined concrete/ferrocement/brick masonry arched type gas holding section and monolithic fixed dome digesters Other

Table 3.2: COMET-Farm Input ranges provided by experts

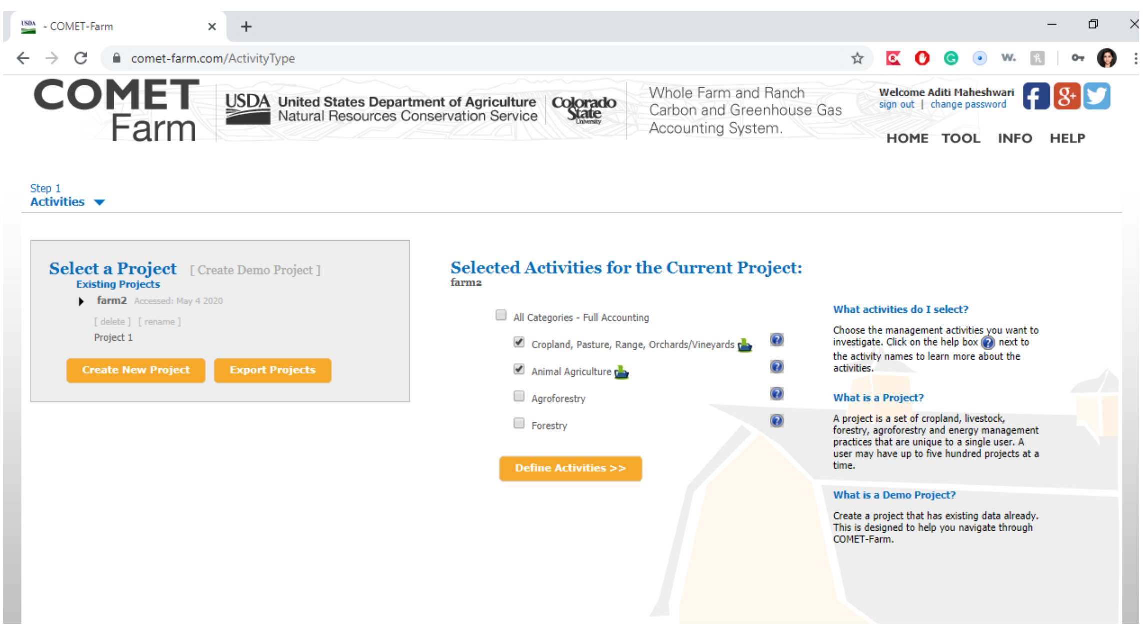


Fig. 3.8: COMET-Farm Parcel Location

After selecting the activity, the next step in running COMET-Farm is to choose field management, which consists of four parts: 1) parcel location, 2) historic management, 3) baseline management and 4) future management. We can select the parcel location either by importing the farm location or drawing the farm manually. A specialist provided, based on Wasatch front farm scenarios, 40 locations of farms, 20 kinds of seasonal and annual crops, and 20 kinds of orchards/vineyards. We choose randomly among these alternatives (uniform probability distribution). After importing the location it will show on the map as a polygon as depicted in Figure 3.8.

The next step is to select historic management where we need to input the history of the management practices as shown in Figure 3.9. Historic management practice is randomly chosen and does not depend on the location parcel. Land can be converted to orchard/vineyard if it was used for annual crop or seasonal crop before, or vice-versa.

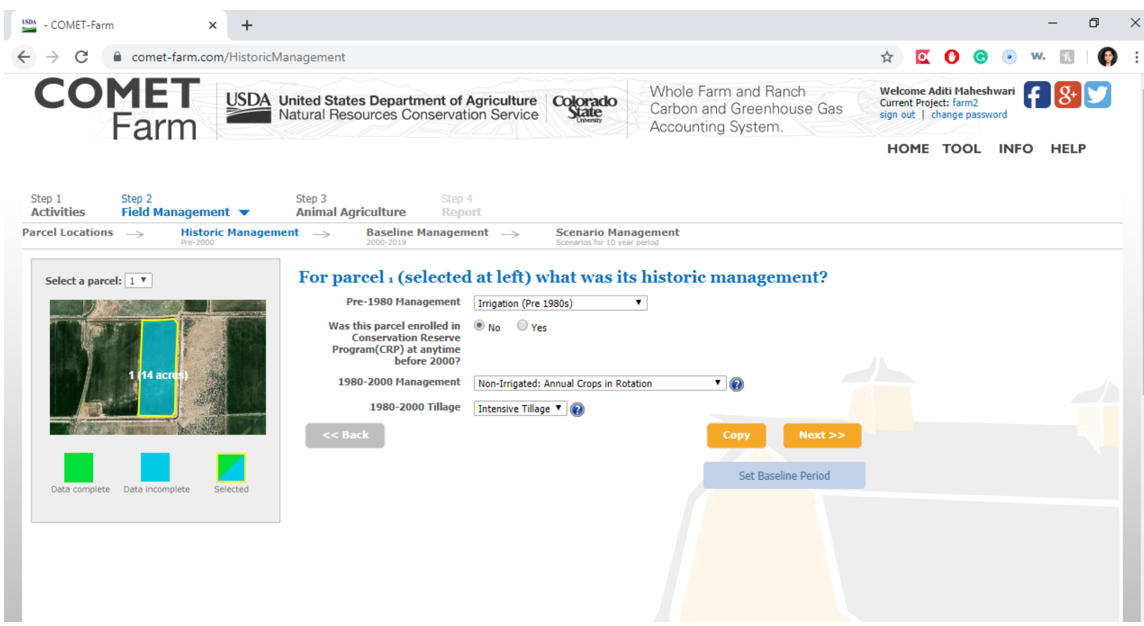


Fig. 3.9: COMET-Farm Historic Management Page

After historic management we need to complete the information for baseline management, which covers the years from 2000 to 2020. We have options to select the type of crop as shown in Figure 3.10. Every crop type has different options and different input fields. We did not choose to rotate crops, instead from 2000 to 2020 we used a single crop. The planting date and harvesting date is input for seasonal and annual crops. Also we had to select the tillage method for the crop and tillage date. Then Fertilizer application details

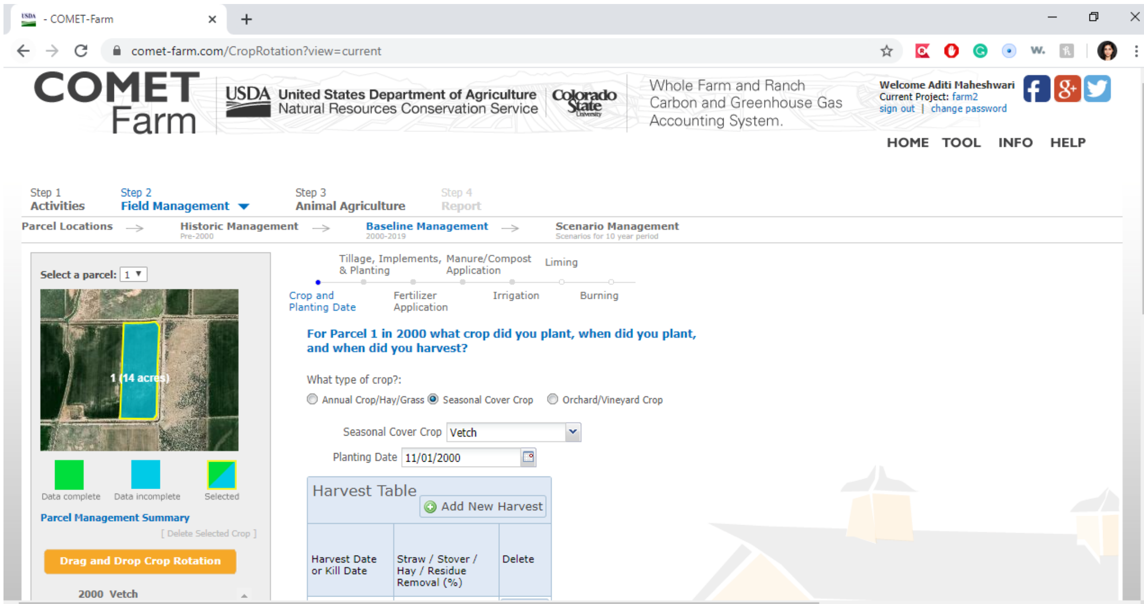


Fig. 3.10: COMET-Farm Baseline Management Crop and Planting Date Page

like type of fertilizer, date for its application and amount needed need to entered for this step. For each type of crop the application date is different depending on the planting date. For Manure/Compost application type of manure which is randomly selection from the choices provided by the specialist. And also date of application and amount applied detail need to be entered. Crop irrigation is a repeated activity done during the crop production. For Orchard/Vineyard irrigation is done every week. For Seasonal crop it also weekly from the planting date to the harvesting date. For Annual crop it needs to repeat every eleven days starting from the planting date and ending at the harvest date. As shown in Figure 3.11 we can enter multiple irrigation scenarios. We can skip the remaining steps since Utah crops are not burnt and no liming is performed.

We use the same crop and management practices from 2000 to 2020. For future management we randomly change one management practice each year out of Tillage type, Manure Type, or Fertilizer type.

The next step is inputting animal agriculture activities to calculate the GHG emissions

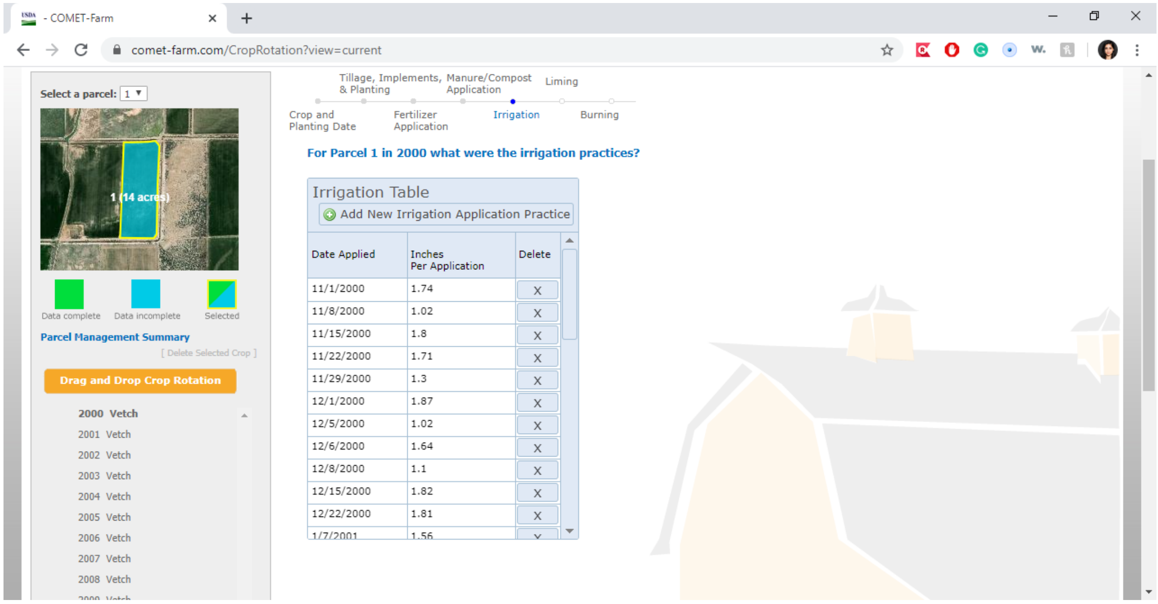


Fig. 3.11: COMET-Farm Baseline Management Irrigation Page

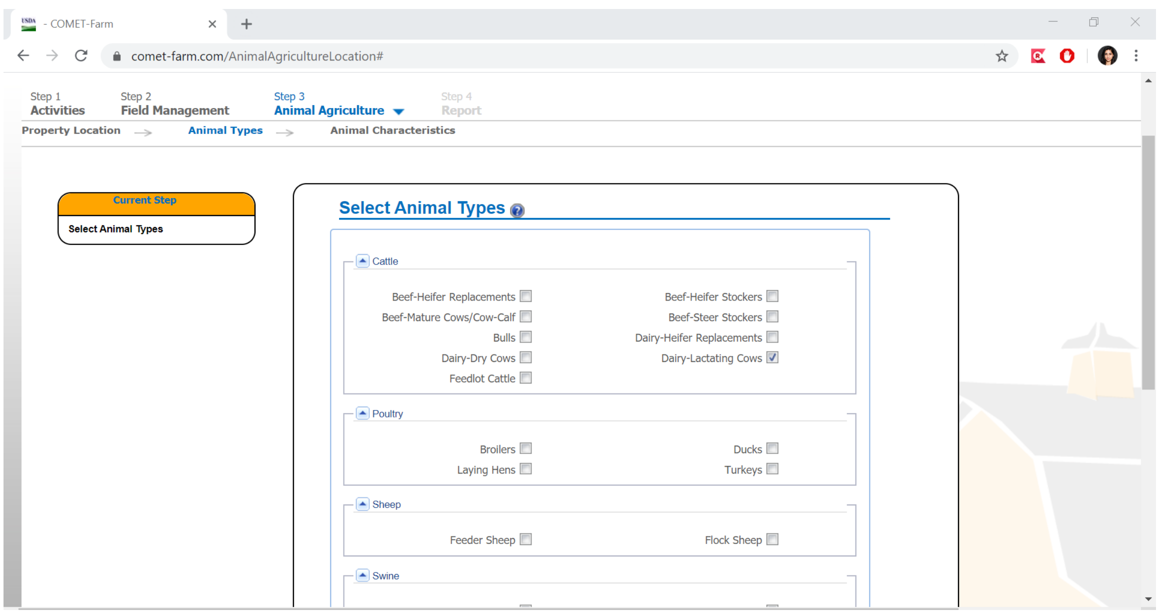


Fig. 3.12: COMET-Farm Animal Agriculture Animal Type Page

by animal agriculture. We can select multiple types of animals in different categories. But for Utah we only select cattle by choosing one category out of Beef-Heifer Stockers, Beef-Steer Stockers, Dairy Lactating Cows, and Feedlot Cattle as shown in Figure 3.12. For each of the cattle types there are different inputs. We then have to choose the number of cattle.

For Beef-Heifer Stockers we need to enter the number of heifers count for each month. In a realistic scenario the stockers count increases or decreases from 1-10. So we choose a random increase or decrease of the count of cattle. Similarly for Beef-Steer Stockers the initial count is taken randomly between 1 to 500 and randomly increases or decreases. For Feedlot cattle we have to count both Heifers and Steers. And for Dairy Lactating Cows we have to enter the count for different categories like Dry Lot, Roofed Facility, and Pasture Range as shown in Figure 3.13. For each category the average body weight of cattle, daily weight gain, and average daily weight is also input.

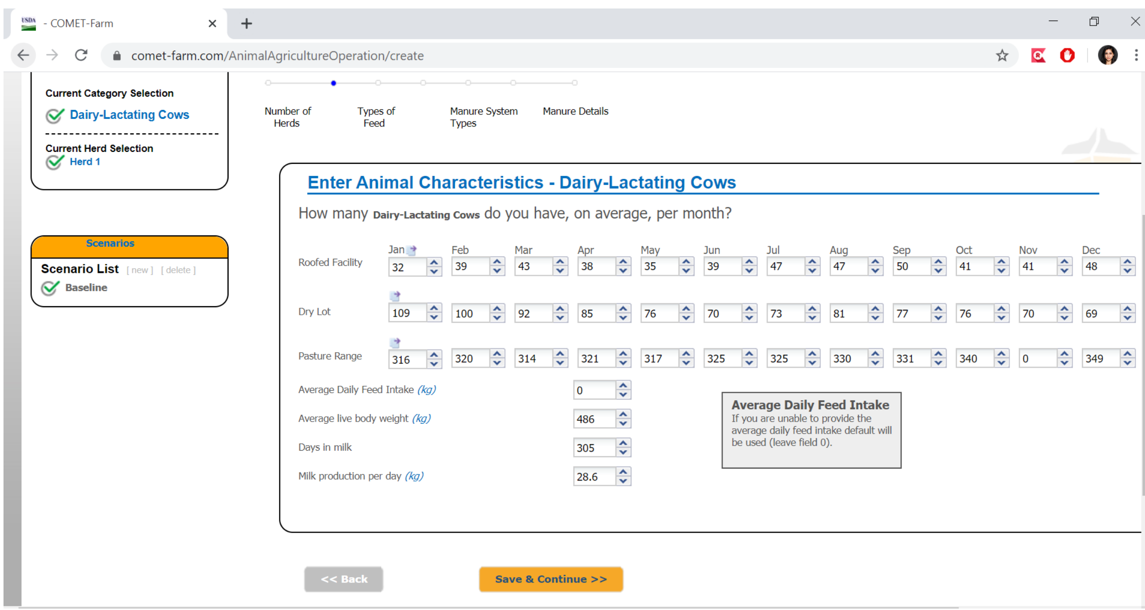


Fig. 3.13: COMET-Farm Animal Agriculture Animal Details page

Feeding activity plays an important role in GHG emissions. We choose the feed type randomly. We choose a single feed type for the year and the percentage of that feed in the diet is 100%. Figure 3.14 shows feed type form.

Next for Dairy-Lactating Cow is housing details. Dairy cows are housed in different types of dairy facilities. In COMET-farm we have pit storage, bedded pack, and flushed or scrapped. We then choose the Manure system types and manure detail. On Manure system it gives option for using solid/liquid separator and if we are using solid/liquid separator we can choose separator type, solid treatment method and liquid treatment method. Page

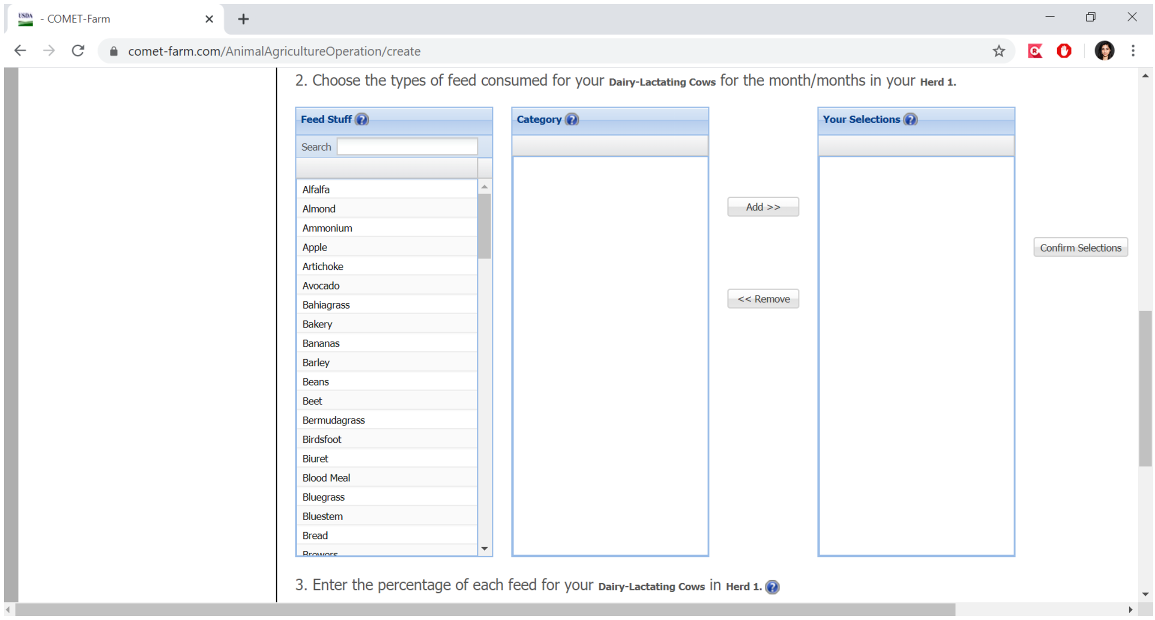


Fig. 3.14: COMET-Farm Animal Agriculture Animal Feed Details Page

next to this depends on what solid and liquid treatment method we have chosen.

For future management for animal agriculture we randomly change a management practice out of feed type or manure detail. After completing all this we can generate GHG report. It takes approximately three minutes to generate the report. For crop production we get C, CO2, N20, CH4 and CO emission as shown in Figure 3.15. We will save GHG emission in our output file for every run. Similarly, for Animal Agriculture it calculates Methane and Nitrous Oxide emission amount as shown in Figure 3.16.

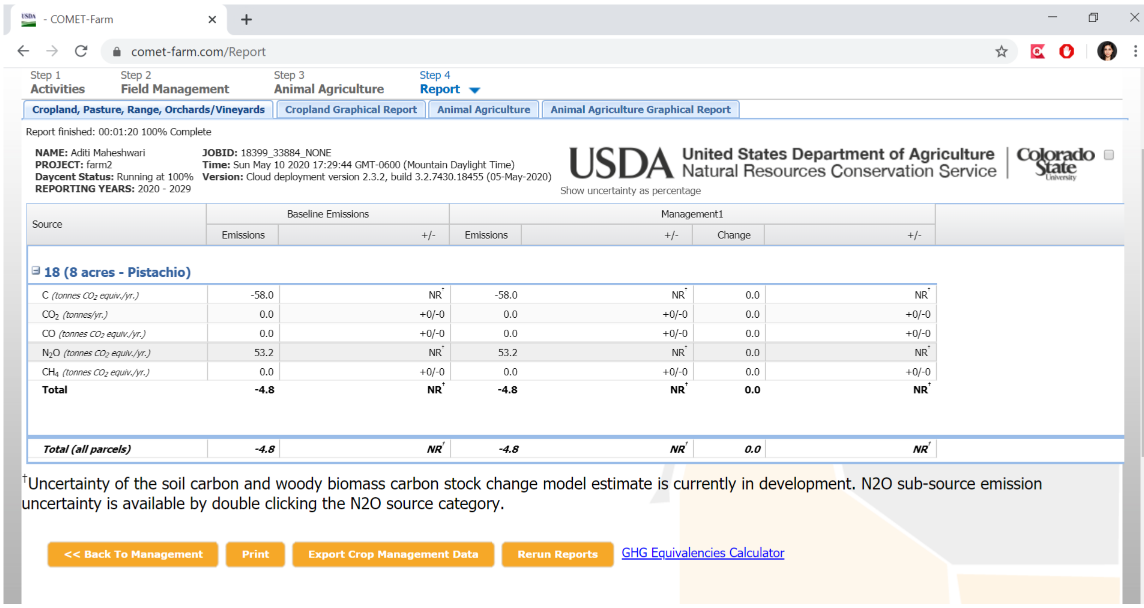


Fig. 3.15: COMET-Farm Crop GHG Emission Report

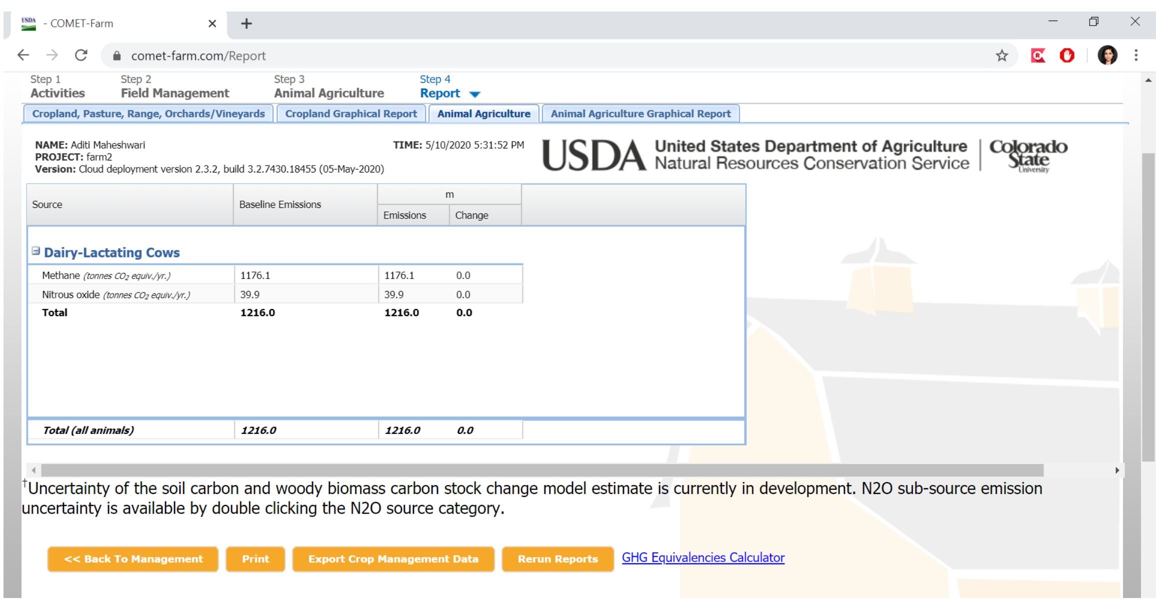


Fig. 3.16: COMET-Farm Animal Agriculture GHG Emission Report

CHAPTER 4

Data Analysis

This chapter describes the analysis of the data generating by automating the whole-farm carbon models as discussed in Chapter 3.

4.1 Analysis Software

We tried several tools for analyzing the data: RapidMiner Studio, Orange and Weka. Weka is a collection of machine learning algorithms for data mining [10]. We decided not to use Weka due to input problems and other usability problems. Orange is a data mining, machine learning and data visualization tool [11]. But we also decided not to use Orange since RapidMiner turned out to have the best interface and more options for the kind of data mining we wanted to do. RapidMiner is data science platform that includes data preparation, machine learning and predictive model deployment [**?**]. Data size and relevance can be transformed using several operations on data [12]. RapidMiner runs several machine learning algorithms like Deep Learning, Generalized Linear Model, Random Forest, Decision tree, Gradient boosted tree, and Support vector machine on the same data simultaneously allowing a user to see differences in the results [12]. We will discuss the analysis of each model for both HOLOS and COMET-Farm in this chapter. We trained the models to obtain minimum relative error so that this model can be used for future data generation using a 70/30 split of training to testing data.

4.2 HOLOS Results

We started with training model with full HOLOS data but the results were complicated since there are 223 attributes in total. So we divided the data into two parts, one for crops and other for animal agriculture.

4.2.1 HOLOS Crop Production Results

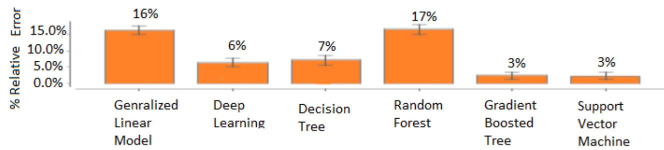


Fig. 4.1: HOLOS Crop Model Relative error Overview

We trained the models on approximately 1200 runs of HOLOS. HOLOS Crop data has 102 attributes and our data contains both nominal and numeric data. Figure 4.1 shows the relative error for each model. Gradient Boosted tree and Support Vector Machine have the least error. Decision Tree and Deep Learning also have low relative error (good accuracy).

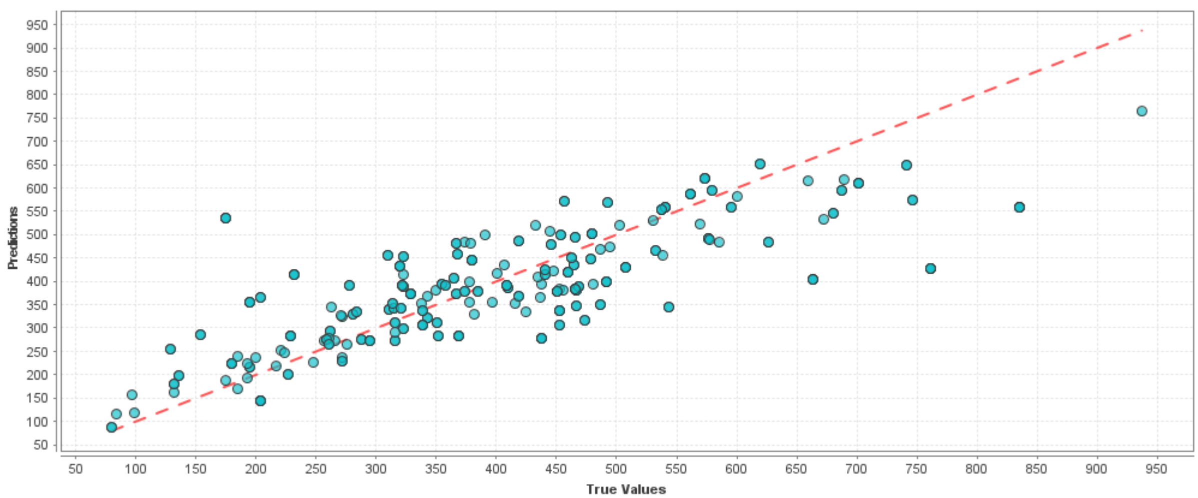


Fig. 4.2: HOLOS Crop Generalized Linear Model Predictions Chart

Figure 4.2 shows the Predictions Chart for Generalized Linear Model. The red dotted line shown in figure is actual values and blue dots are predicted value. The prediction chart for random forest is shown in Figure 4.4. Figure 4.3, Figure 4.7 shows Predictions Chart for Deep Learning method and Random Forest method, in these models relative error percentage is 6 and 7% respectively.

Decision tree model produces a tree shown in Figure 4.9. It is a big tree because we have 102 attributes for HOLOS crop data. This tree is further shown different parts to

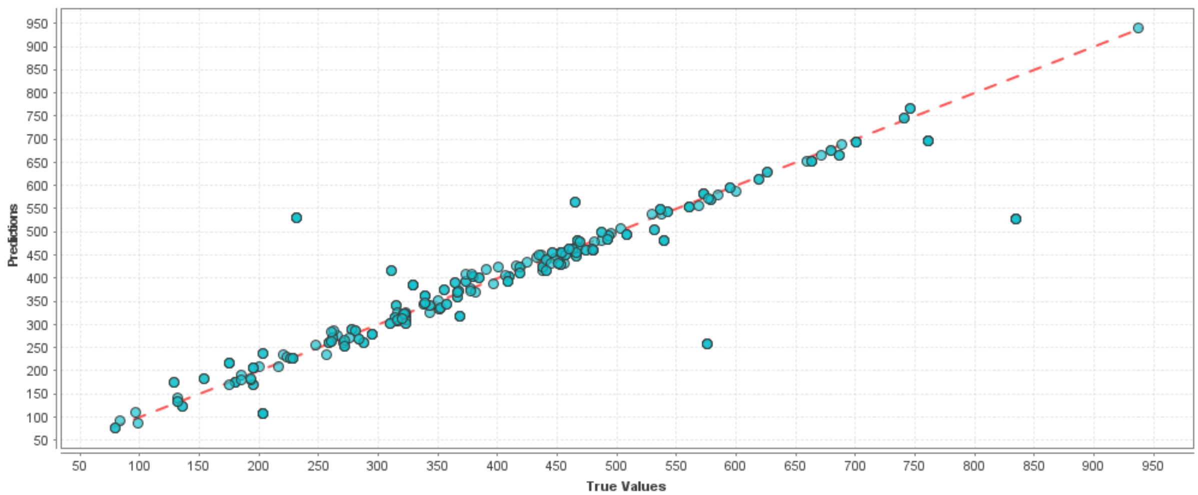


Fig. 4.3: HOLOS Crop Deep Learning Predictions Chart

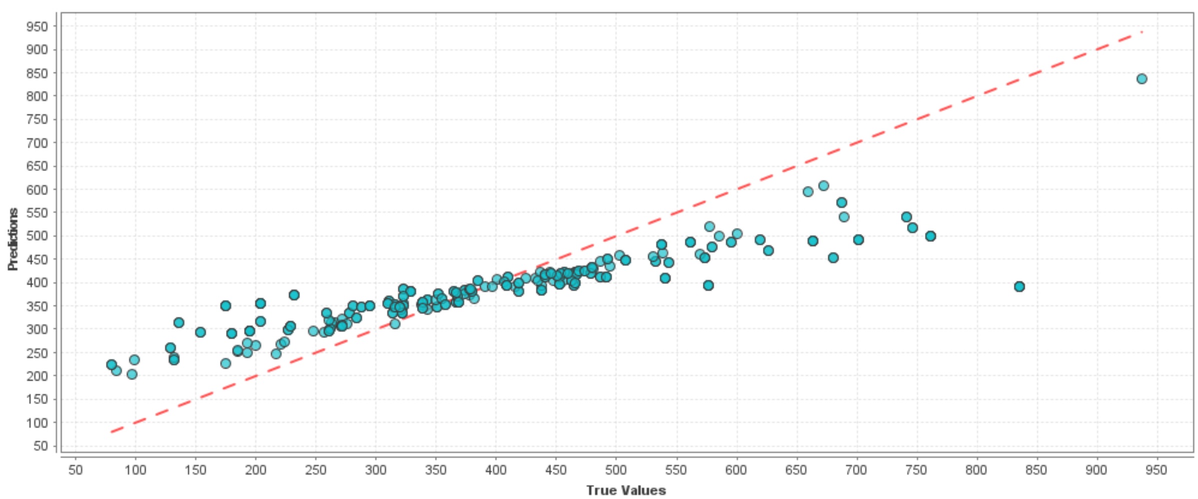


Fig. 4.4: HOLOS Crop Random Forest Predictions Chart

understand each branch properly. This tree would help farmers to choose management practices for the farms as it shows how practices impact GHG emissions. In Figure 4.10 it shows the topography (physical feature of an area) is the top most factor of GHG emission and other two branches shows Irrigation activity and year in which crop got seeded. The second part of decision tree is shown in Figure 4.11 which describes how Year seeded, Soil Type, Yield, and Soil N20 breakdown for month January is affecting the emissions. Similarly, other parts of tree is shown in Figure 4.12, Figure 4.13, Figure 4.14, Figure 4.15, and Figure 4.12 which shows dependence of attributes on GHG emissions.

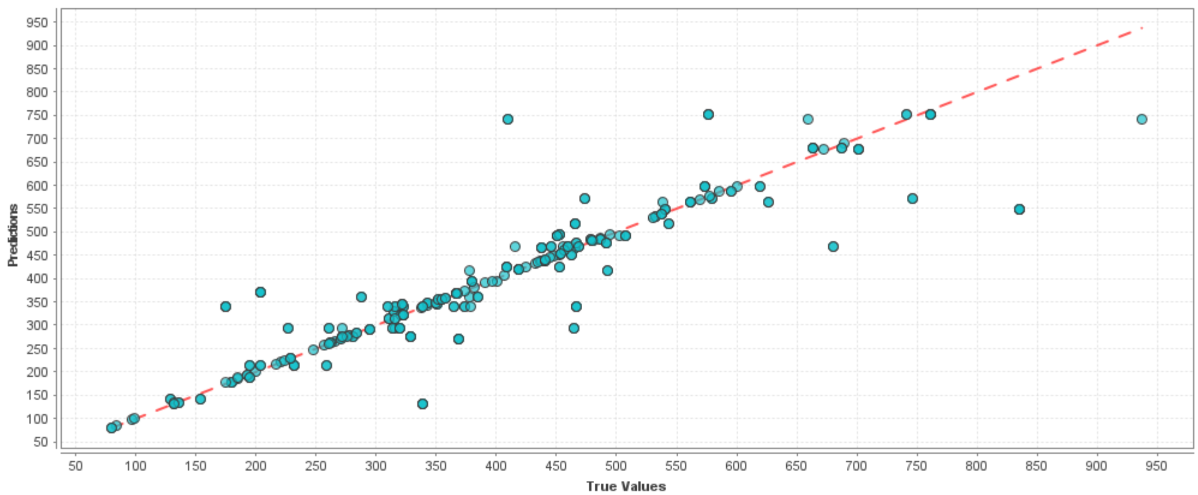


Fig. 4.5: HOLOS Crop Decision Tree Predictions Chart

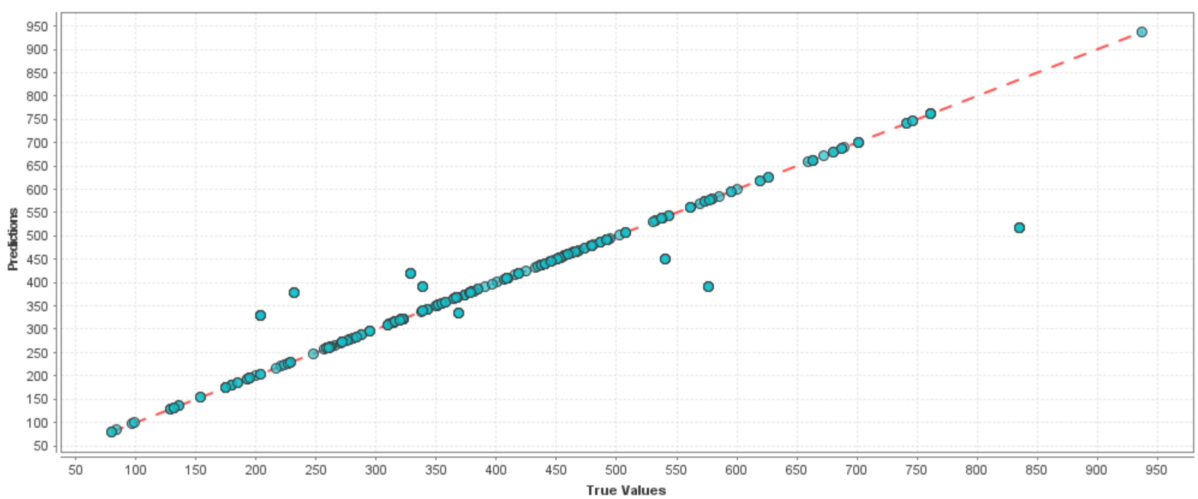


Fig. 4.6: HOLOS Crop Support Vector Machine Predictions Chart

RapidMiner provides a feature to see the weights of all the attributes for a model. Figure 4.17 shows a table with all the attributes weights. F topography has the highest affect on GHG emissions. Irrigation activities which depend on precipitation also has high impact. This table also shows which management practice has higher weight. For tillage management it shows that Reduced is better that No till. Also it tells which soil and soil texture is better to have. We have consulted with experts with the results and concluded that the results we got is practical.

In summary the Gradient Boosted Tree Model and Support Vector Machine had the

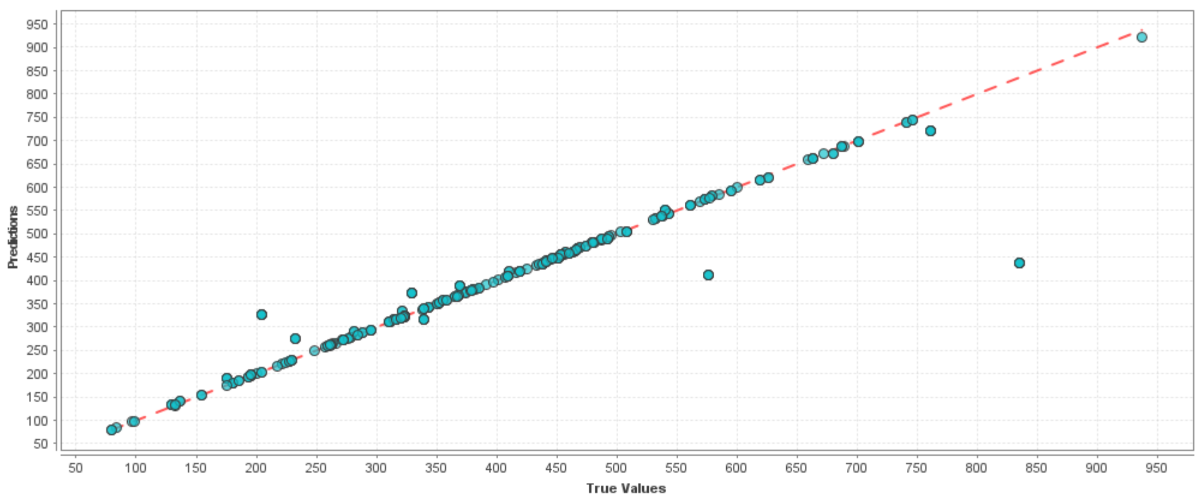


Fig. 4.7: HOLOS Crop Gradient Boosted Tree Predictions Chart

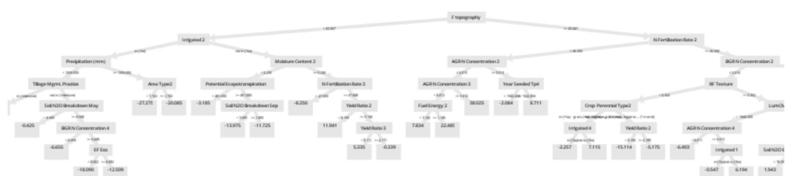


Fig. 4.8: HOLOS Crop Gradient Boosted Tree

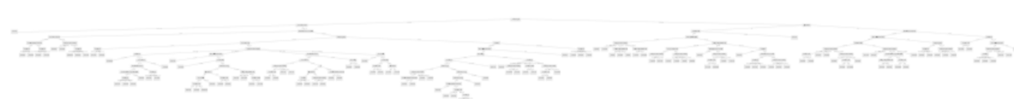


Fig. 4.9: HOLOS Crop Decision Tree Model

lowest relative error, 3%. The Decision Tree Model produced a decision tree that could help farmers choose the best management practices.

4.2.2 HOLOS Animal Agriculture Results

The HOLOS animal agriculture data set had 1500 runs with each run having 156 attributes. Figure 4.18 shows relative error for all six models. For HOLOS animal agriculture

Fig. 4.10: HOLOS Crop Decision Tree Model Part 1

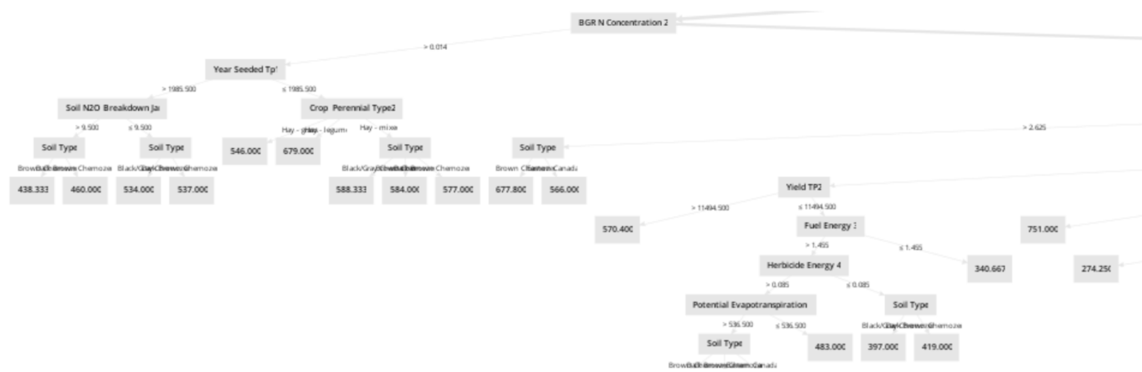


Fig. 4.11: HOLOS Crop Decision Tree Model Part 2

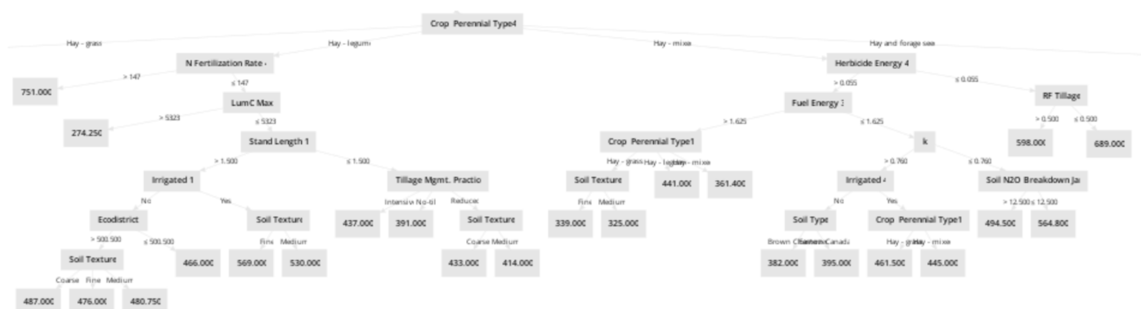


Fig. 4.12: HOLOS Crop Decision Tree Model Part 3

the Gradient Linear Model, Deep Learning, Decision Tree and Support Vector Machine models have about a 5% relative error. Gradient Boosted tree has the lowest relative error, 2%.

Figure 4.19, Figure 4.20, Figure 4.21, Figure 4.23, and Figure 4.24 show the prediction

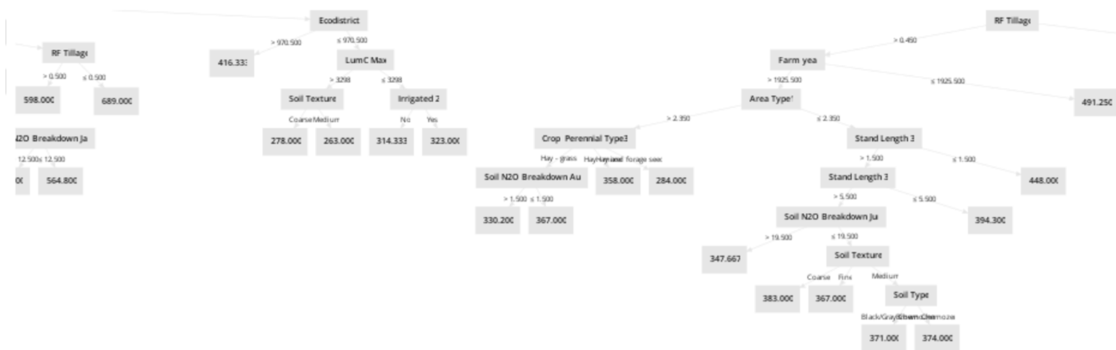


Fig. 4.13: HOLOS Crop Decision Tree Model Part 4

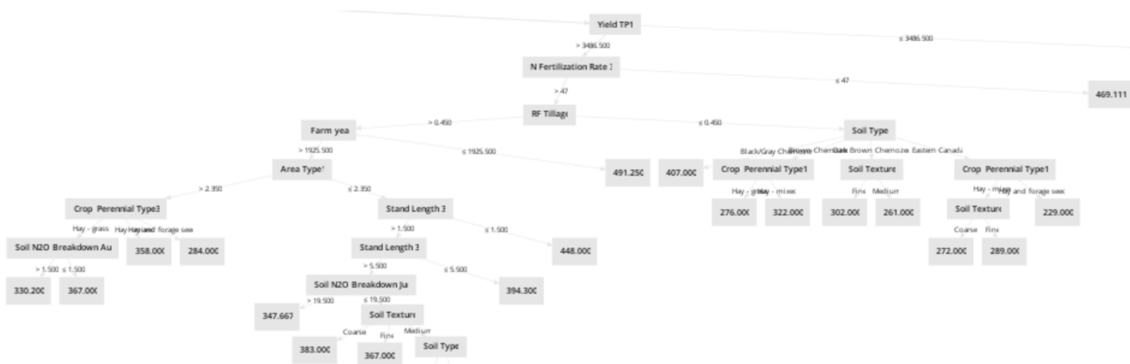


Fig. 4.14: HOLOS Crop Decision Tree Model Part 5

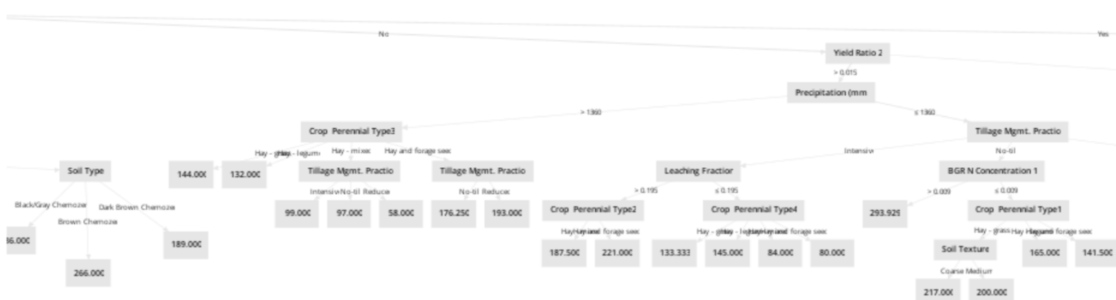


Fig. 4.15: HOLOS Crop Decision Tree Model Part 6

models for Generalized Linear Model, Deep Learning Model, Decision Tree Model, Gradient Boosted Tree and Support Vector Machine, respectively. We can see how predicted values, which is shown by blue dots, is on or very near the actual value, which is indicated by red dotted line.

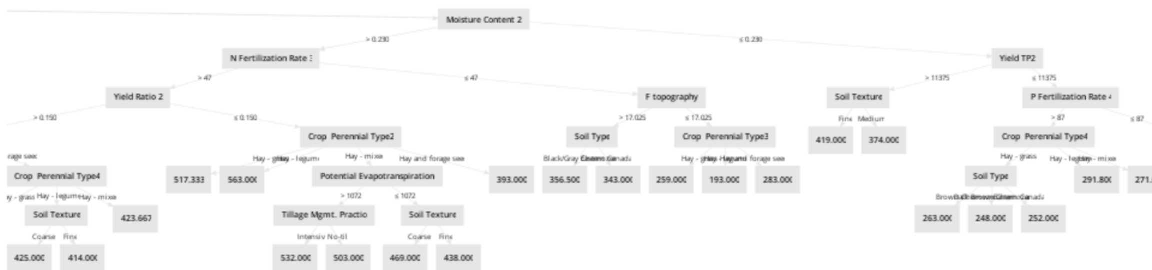


Fig. 4.16: HOLOS Crop Decision Tree Model Part 7

In Figure 4.22 Predictions Chart for Random Forest Model is shown. For Random Forest relative error is 10%. There are many outliers, which represent less accurate predictions.

The Decision Tree Model produces a decision tree which is shown in Figure 4.26. For better readability parts of the tree are depicted in Figure 4.27, Figure 4.28, Figure 4.29, Figure 4.30, and Figure 4.31. In Figure 4.27 the decision tree is showing dependency between Housing System and Manure System. When the Housing system is Enclosed Pasture the least GHG emission is occurred when the Manure System is Compost Passive and Custom. The numbers in the attributes in the figure represent different months, e.g., 1 represents January, 2 represents February, etc. Figure 4.28 shows the relationship between Manure System and Diet Additive and also Diet Additive and Soil Type. Figure 4.29 depicts the dependency of Soil Breakdown in January with Soil Type. One interesting relationship is between the number of heifers in May (heifer 5) with Manure System 8 and Soil texture, When the heifers number more than 624 if we choose the Manure System as pasture there will be least emission of GHG. Similarly, other relationships between different management practices are shown in Figure 4.29, Figure 4.30, and Figure 4.31. The decision tree will help farmers to decide which management practice(s) will produce less GHGs.

HOLOS Animal Agriculture attribute weight distribution is shown in Figure 4.32. Steer10 (Steer count in October) has the highest impact on emissions. And Compost Intensive Manure System highly impacts GHG emissions. The count of steers and Heifers also

Attribute	Weight
F topography	0.536
Irrigated 2 = No	0.315
Irrigated 4 = Yes	0.243
Irrigated 3 = Yes	0.227
Irrigated 1 = No	0.221
RF Texture	0.204
Crop Perennial Type1 = Hay - mixed	0.173
Leaching Fraction	0.143
Fuel Energy 4	0.140
Precipitation (mm)	0.138
Moisture Content 3	0.119
AGR N Concentration 1	0.118
Stand Length 3	0.116
BGR N Concentration 2	0.113
P Fertilization Rate 4	0.112
Herbicide Energy 4	0.107
Crop Perennial Type1 = Hay - grass	0.106
Crop Perennial Type4 = Hay - legume	0.102
Crop Perennial Type3 = Hay - grass	0.102
Yield TP1	0.099
Crop Perennial Type2 = Hay - mixed	0.098
RF Tillage	0.091
N Fertilization Rate 2	0.088
Year Seeded Tp2	0.087
Crop Perennial Type2 = Hay - legume	0.085
Stand Length 2	0.078
Year Seeded Tp1	0.076
Crop Perennial Type3 = Hay - mixed	0.075
Yield Ratio 2	0.074
Yield TP4	0.074
Soil N2O Breakdown Apr	0.070
Area Type3	0.069
Yield Ratio 1	0.068
N Fertilization Rate 3	0.068
Herbicide 4 = Yes	0.067
Soil N2O Breakdown Jan	0.064
Herbicide 3 = No	0.064
P Fertilization Rate 2	0.063
k	0.059
Yield TP3	0.057
Tillage Mgmt. Practice = No-till	0.057
Past Tillage Intensity = No-till	0.057
Moisture Content 4	0.056
Area Type2	0.056

Fig. 4.17: HOLOS Crop Attribute Weights

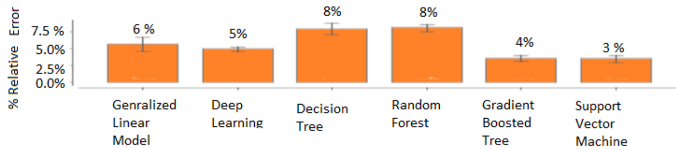


Fig. 4.18: HOLOS Animal Agriculture Models Relative error Overview

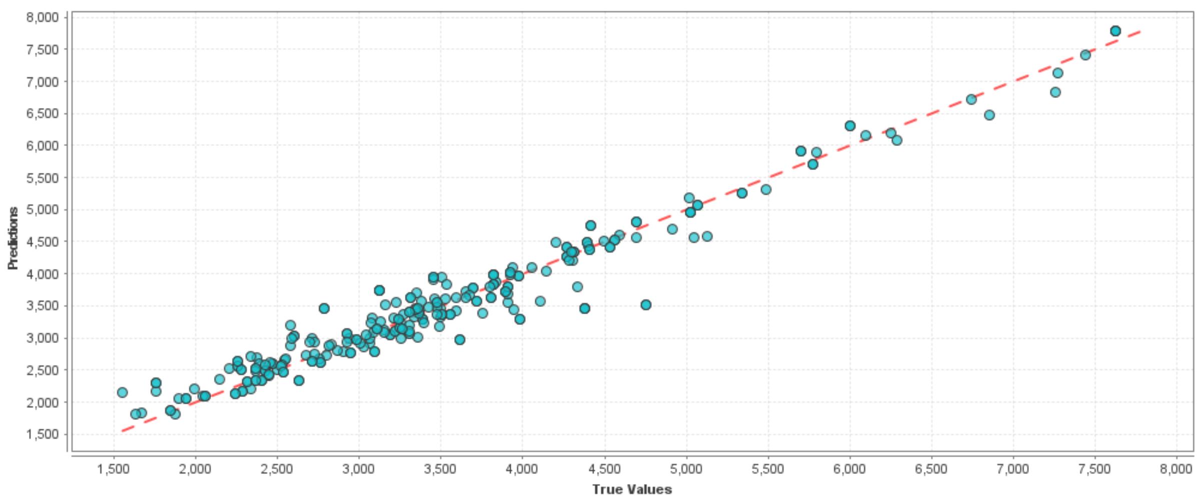


Fig. 4.19: HOLOS Animal Agriculture Generalized Linear Model Predictions Chart

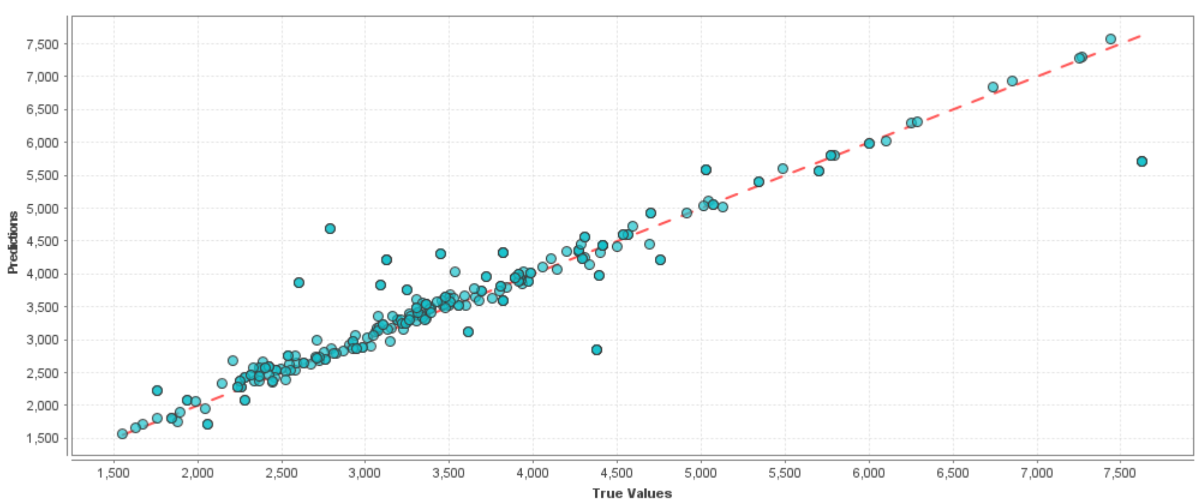


Fig. 4.20: HOLOS Animal Agriculture Deep Learning Predictions Chart

impacts emissions (not surprisingly).

Gradient Boosted Tree model has the highest accuracy rate with 2% relative error. We will use this model for prediction.

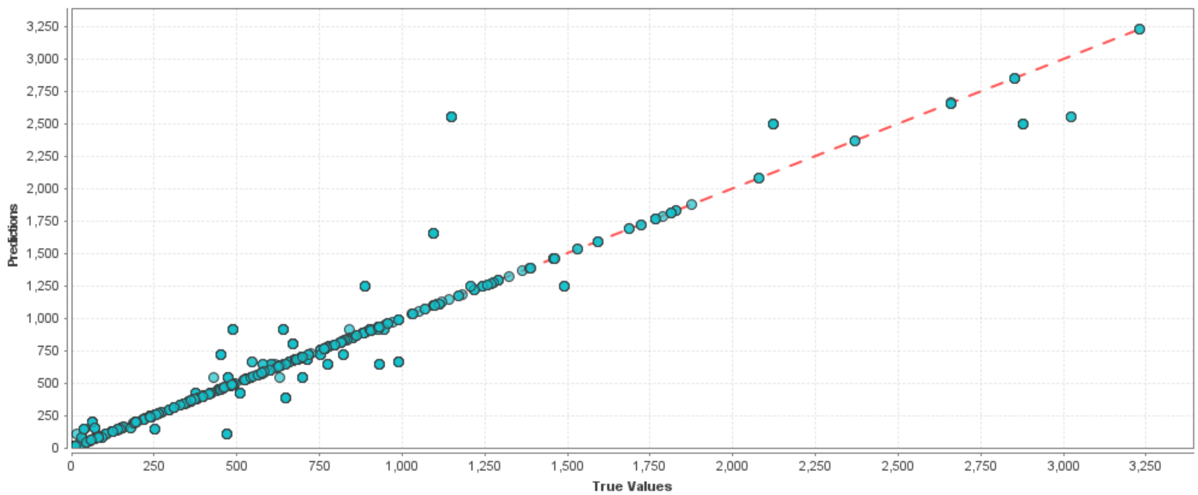


Fig. 4.21: HOLOS Animal Agriculture Decision Tree Predictions Chart

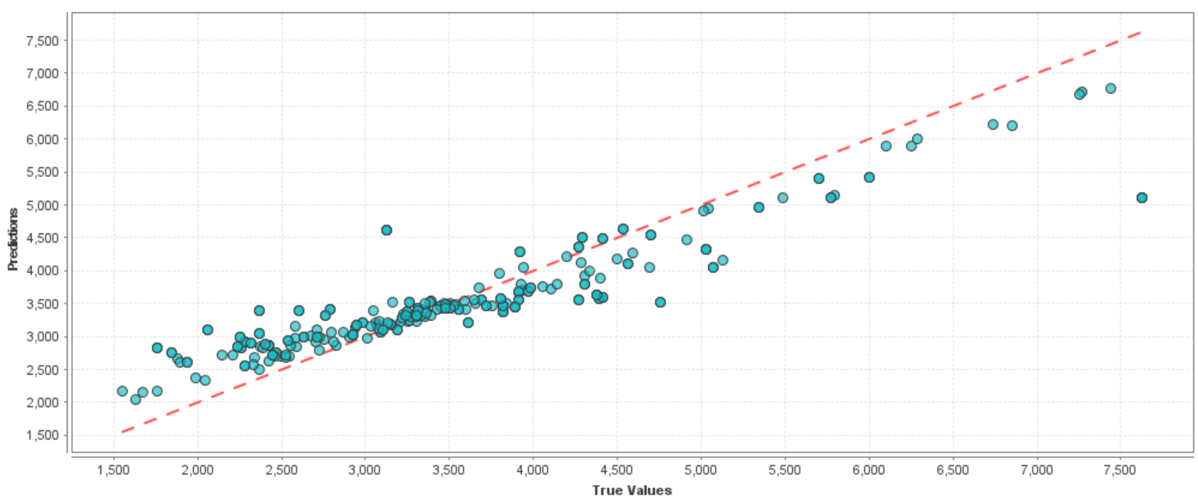


Fig. 4.22: HOLOS Animal Agriculture Random Forest Predictions Chart

4.3 COMET-Farm Results

For COMET-Farm we collected around 5000 runs. Each run has 351 total attributes. To reduce the number of attributes for analysis we divided the attributes into six parts. Each of the three different types of crop formed a part and we grouped the four different types of animals into three parts: Heifer and Steer data were combined while Feedlot Cattle and Dairy-Lactating Cows attributes each formed a part. Since not every run had data for a particular part, e.g., a farm may not have had Feedlot Cattle, the number of rows with data for a particular attribute set varies.

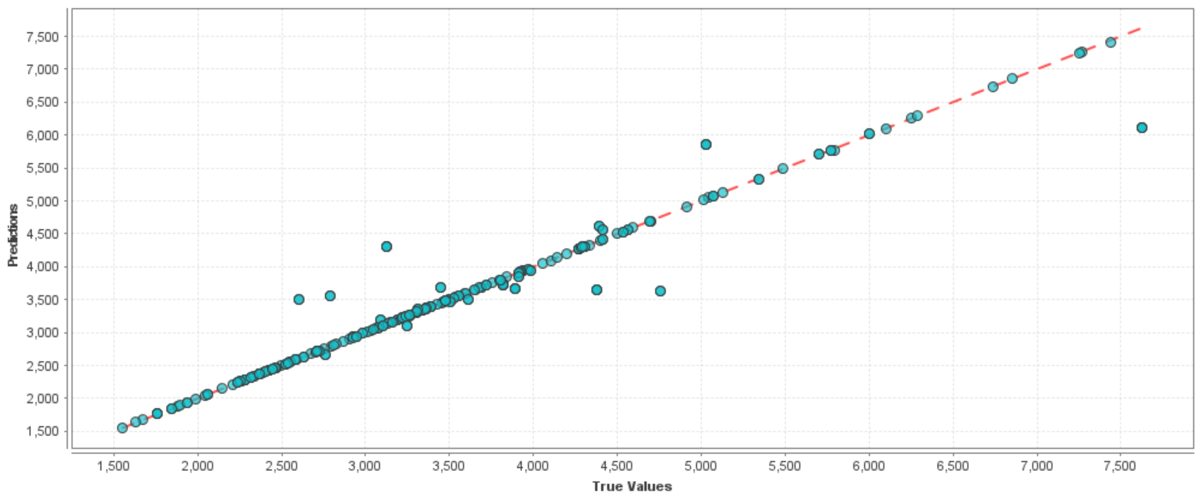


Fig. 4.23: HOLOS Animal Agriculture Gradient Boosted Tree Predictions Chart

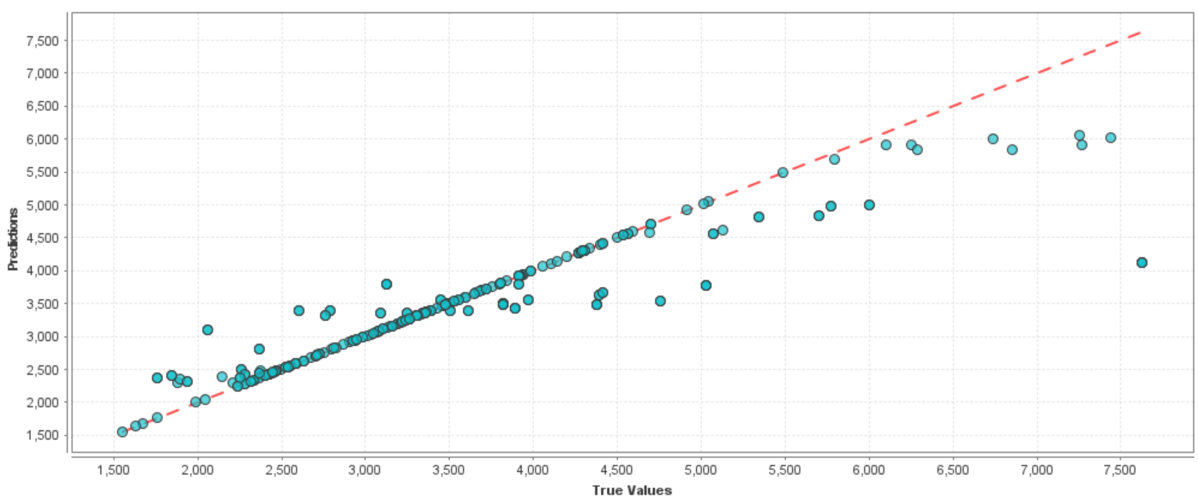


Fig. 4.24: HOLOS Animal Agriculture Support Vector Machine Predictions Chart

Fig. 4.25: HOLOS Animal Agriculture Gradient Tree

Fig. 4.26: HOLOS Animal Agriculture Decision Tree

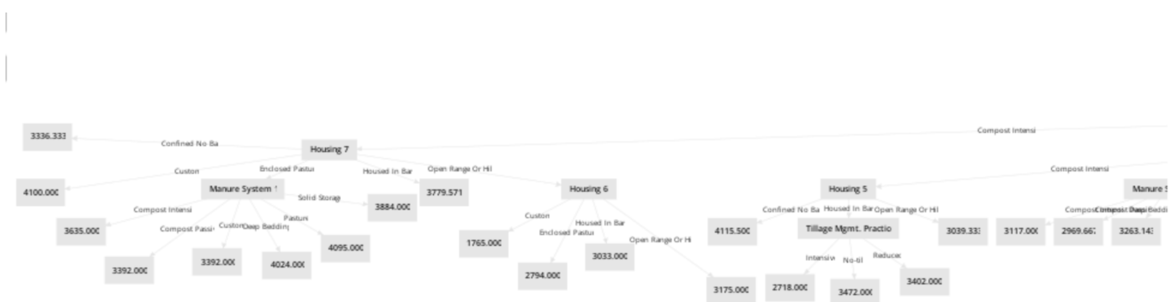


Fig. 4.27: HOLOS Animal Agriculture Decision Tree Part 1

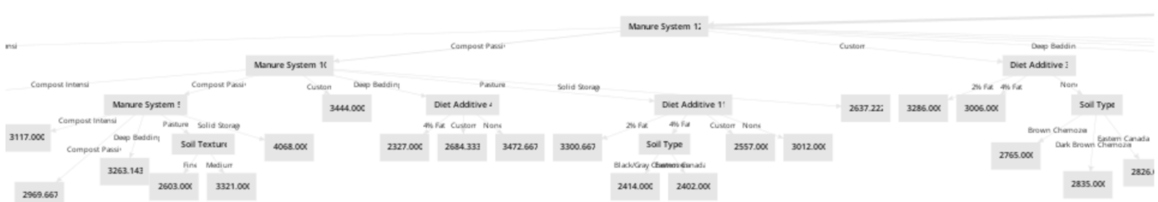


Fig. 4.28: HOLOS Animal Agriculture Decision Tree Part 2

4.3.1 COMET-Farm Crop Production Results

There are three different types of crops Orchard/Vineyard, Seasonal Crop, and Annual Crop in COMET-Farm. We divided COMET-Farm Crop attributes into these three types of crops, since the attributes vary by crop type. We will discuss results of each crop type in sections below.

The COMET-Farm Orchard/Vineyard Crop type has 128 attributes over 1000 runs.

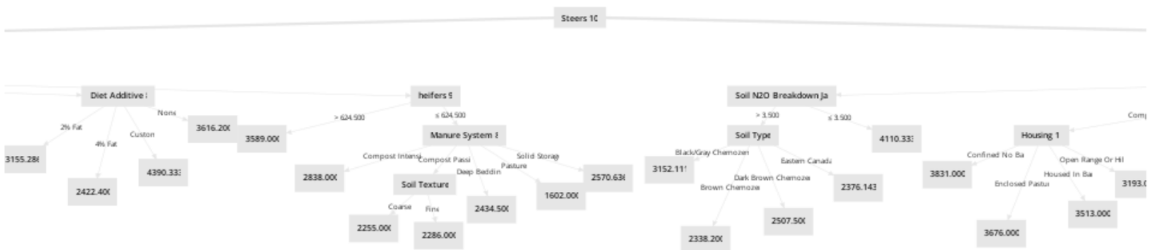


Fig. 4.29: HOLOS Animal Agriculture Decision Tree Part 3

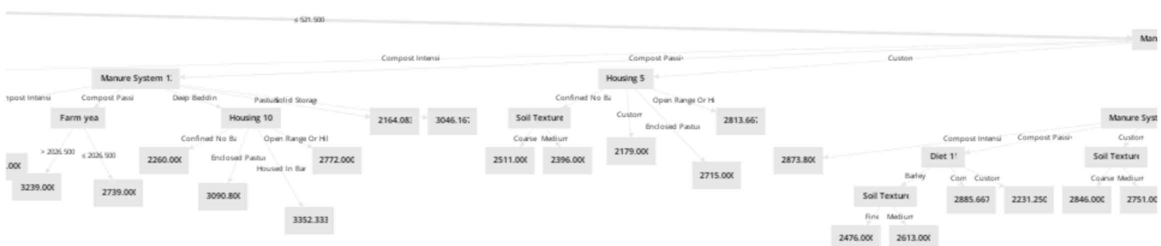


Fig. 4.30: HOLOS Animal Agriculture Decision Tree Part 4

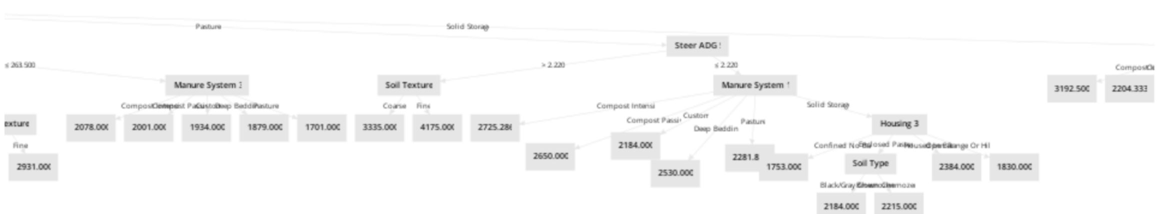


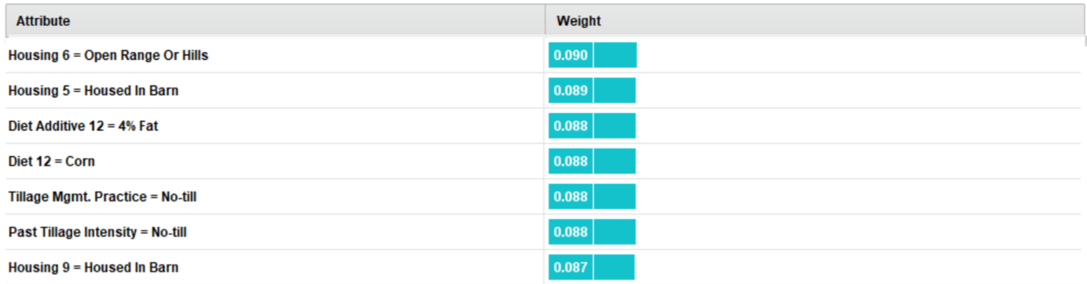
Fig. 4.31: HOLOS Animal Agriculture Decision Tree Part 5

Support Vector Machine has the smallest relative error as shown in Figure 4.33. Figure 4.34 shows Predictions Chart for Generalized Linear Model, relative error for this model is 27%. For Deep Learning Model and Random Forest Model Predictions Chart is shown in Figure 4.35 and Figure 4.35 respectively. Relative error is high for these models. Similarly, Figure 4.36 shows the Predictions Chart for Decision Tree Model and Figure 4.36 shows Gradient

Attribute	Weight
Steers 10	0.287
Manure System 12 = Compost Intensive	0.263
Manure System 9 = Compost Intensive	0.258
Steers 11	0.250
Manure System 10 = Compost Intensive	0.245
Manure System 6 = Compost Intensive	0.236
Manure System 8 = Compost Intensive	0.235
heifers 9	0.217
Heifer ADG 12	0.212
heifers 12	0.210
heifers 6	0.207
Housing 8 = Open Range Or Hills	0.204
Diet Additive 2 = 2% Fat	0.202
heifers 10	0.200
Steers 6	0.177
Steers 5	0.173
Manure System 7 = Compost Intensive	0.173
Manure System 5 = Compost Intensive	0.171
Housing 4 = Open Range Or Hills	0.168
Manure System 11 = Compost Intensive	0.161
Manure System 1 = Compost Intensive	0.158
Manure System 9 = Compost Passive	0.156
Manure System 12 = Deep Bedding	0.156
Steers 1	0.148
Manure System 8 = Compost Passive	0.145
Diet Additive 10 = 2% Fat	0.145
Diet Additive 11 = Custom	0.142
Diet Additive 2 = None	0.138
heifers 3	0.134
Housing 6 = Enclosed Pasture	0.134
heifers 7	0.132
Heifer ADG 1	0.131

Boosted Tree Model. There are fewer outliers in these Predictions Chart as relative error is 6% and 8%, respectively. Figure 4.40 shows one of the trees generated by Gradient Boosted Tree model. And Figure 4.36 shows the decision tree. Figure 4.42, Figure 4.43, Figure 4.44 and Figure 4.45 shows different parts of decision tree. Figure 4.42 shows how different Fertilizer types impact GHG emissions and also the dependency of different types of crops on Manure Type. A farmer can rank the different management practices to reduce the GHG emissions.

Attribute	Weight
Steer ADG 1	0.114
Housing 4 = Confined No Barn	0.114
Housing 8 = Housed In Barn	0.113
Housing 6 = Housed In Barn	0.112
Initial Heifer Weight 8	0.112
Diet 8 = Corn	0.112
Diet Additive 11 = 4% Fat	0.111
Initial Heifer Weight 2	0.111
Diet 1 = Corn	0.110
Tillage Mgmt. Practice = Reduced	0.109
Past Tillage Intensity = Reduced	0.109
Housing 1 = Open Range Or Hills	0.107
Manure System 8 = Custom	0.107
Housing 1 = Confined No Barn	0.107
Manure System 3 = Compost Intensive	0.106
Housing 7 = Open Range Or Hills	0.106
Diet Additive 7 = None	0.106
Initial Steer Weight 8	0.105
Steer ADG 5	0.105
Heifer ADG 9	0.104
heifers 8	0.104
Diet Additive 8 = Custom	0.103
heifers 11	0.102
Initial Steer Weight 1	0.102
Diet Additive 4 = None	0.101
Manure System 10 = Pasture	0.101
Steer ADG 6	0.100
Steers 9	0.099
Soil Type = Brown Chernozem	0.099
Diet Additive 9 = 4% Fat	0.099
Manure System 6 = Compost Passive	0.098
Housing 3 = Open Range Or Hills	0.098
Housing 9 = Confined No Barn	0.097
Diet Additive 8 = None	0.097
Diet Additive 7 = 2% Fat	0.097
Housing 7 = Housed In Barn	0.096
Steers 3	0.096
Housing 12 = Open Range Or Hills	0.096
Housing 9 = Enclosed Pasture	0.095
Manure System 10 = Solid Storage	0.094
RF Texture	0.093
Diet Additive 2 = 4% Fat	0.092
Diet 3 = Barley	0.091
Initial Heifer Weight 5	0.091



Attribute	Weight
Housing 6 = Open Range Or Hills	0.090
Housing 5 = Housed In Barn	0.089
Diet Additive 12 = 4% Fat	0.088
Diet 12 = Corn	0.088
Tillage Mgmt. Practice = No-till	0.088
Past Tillage Intensity = No-till	0.088
Housing 9 = Housed In Barn	0.087

Fig. 4.32: HOLOS Animal Agriculture Attribute Weights

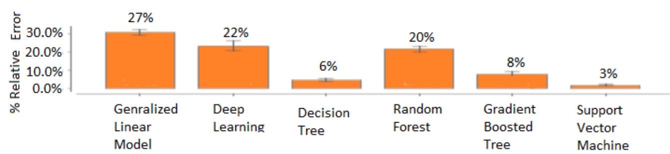


Fig. 4.33: COMET-Farm Orchard/Vineyard Crop Regression Models Relative error Overview

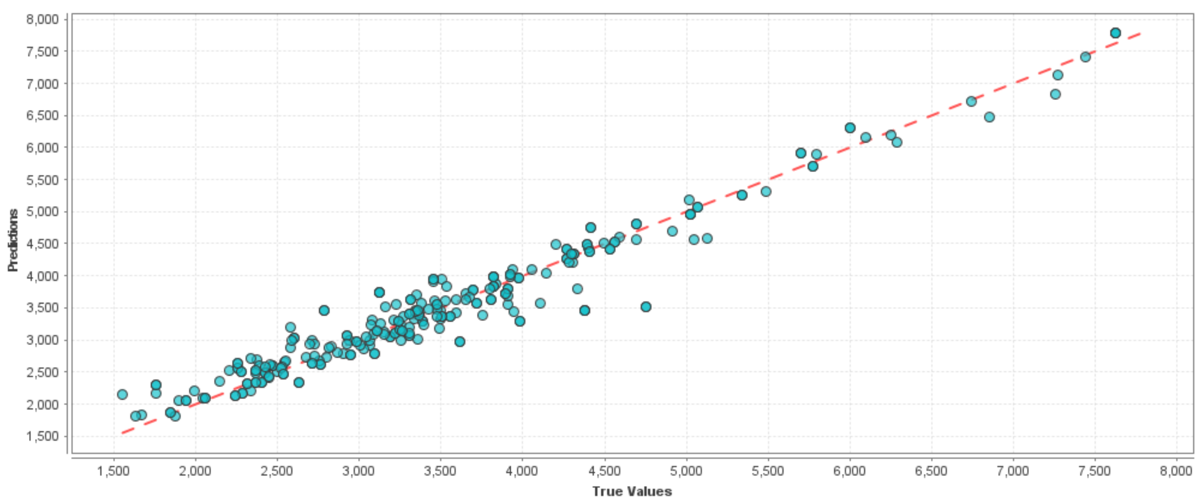


Fig. 4.34: COMET-Farm Orchard/Vineyard Crop Generalized Linear Model Predictions Chart

4.3.2 COMET-Farm Annual Crop Results

The Annual Crop part has around 1400 runs, each with 129 attributes. Figure 4.47 shows the overall relative error of all six models. Generalized Linear Model Predictions Chart is shown in Figure 4.48 which shows scattered predicted values. Accuracy of this model is low with 29% of relative in comparison to other models. Similarly, Predictions

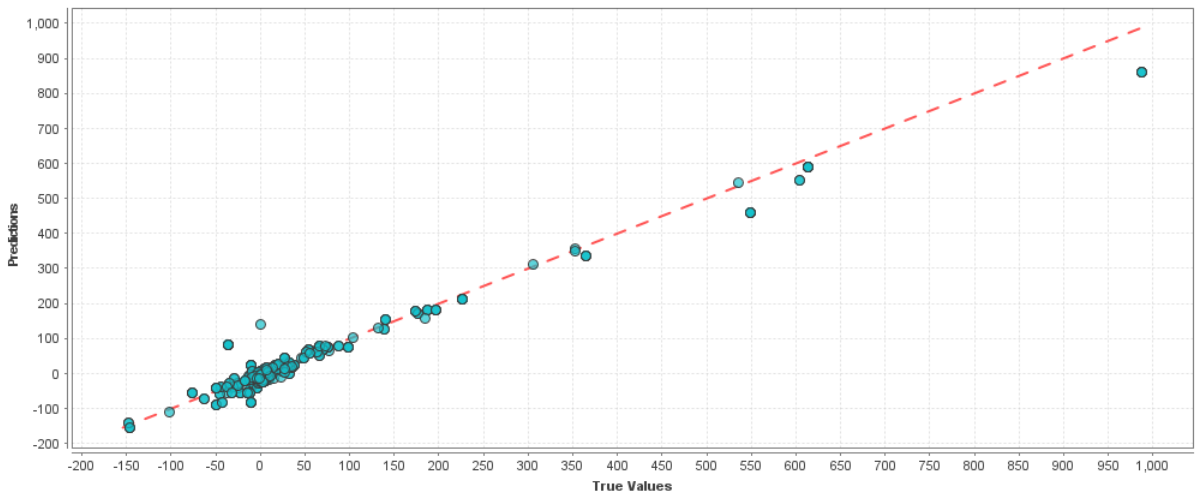


Fig. 4.35: COMET-Farm Orchard/Vineyard Crop Deep Learning Predictions Chart

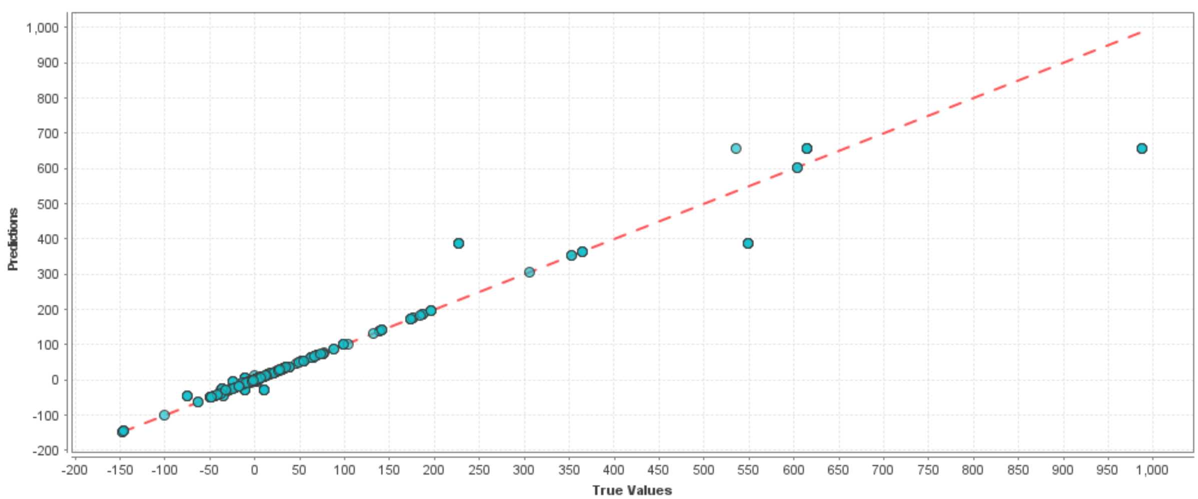


Fig. 4.36: COMET-Farm Orchard/Vineyard Crop Decision Tree Predictions Chart

Chart of Deep Learning Model and Random Forest Model are given in Figure 4.49 and Figure 4.51. Relative error for these models are 20% and 17% respectively. Decision Tree Model predicted results with 4% relative error. Predictions Chart for Decision Tree is shown in Figure 4.50. As we can see it has few outliers and most of the predicted values lie on the actual value line. Decision tree also generated a Decision Tree shown in Figure 4.55. This a large tree. This tree is further shown in parts for closer look which we can see in Figure 4.56, 4.57, 4.58, and 4.59. In Figure 4.53 the Predictions Chart of Gradient Boosted tree is shown. This model gives 8% of relative error. A Gradient Boosted tree is shown in Figure

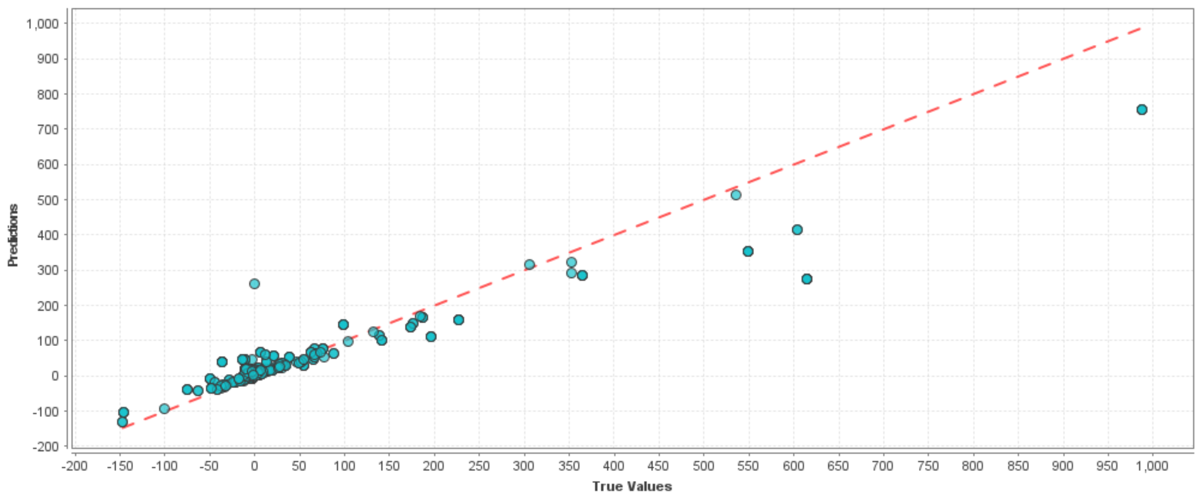


Fig. 4.37: COMET-Farm Orchard/Vineyard Crop Random Forest Predictions Chart

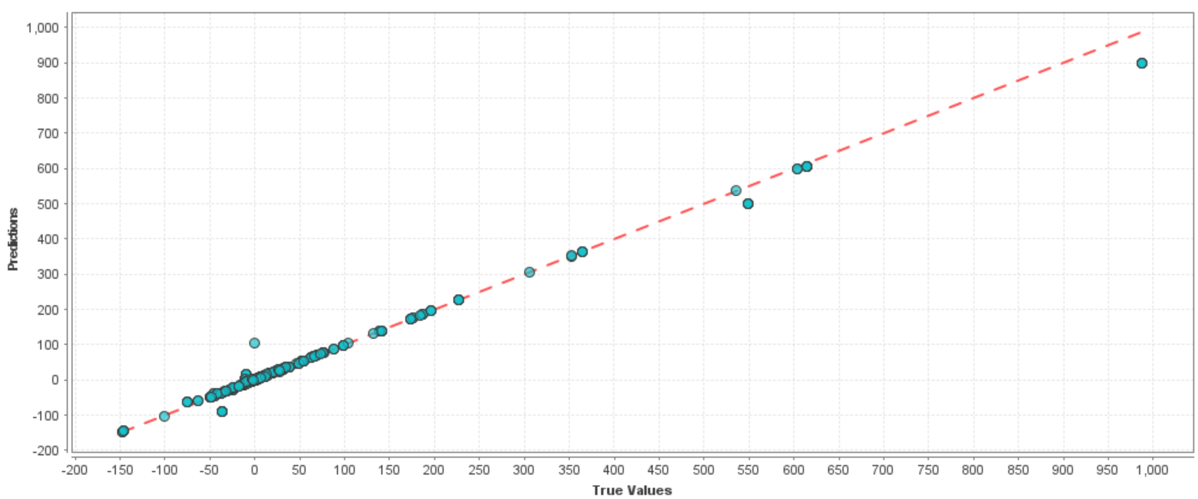


Fig. 4.38: COMET-Farm Orchard/Vineyard Crop Gradient Boosted Tree Predictions Chart

4.52. Attributes weights by which they are impacting the result is shown in Figure 4.60. This figure and the Decision Tree's shown above is used to take decisions while farming to reduce the GHG emission by choosing the right management practices. The best model with 2% of accuracy rate is Support Vector Machine Model. Predictions Chart for it is shown in Figure 4.54.

For COMET-Farm Seasonal crop we collected around 1200 runs data. This data has 130 attributes. Figure 4.61 shows relative error for all the models. Figure 4.48 shows Predictions Chart Generalized Linear Model with 28% relative error. This model gives the

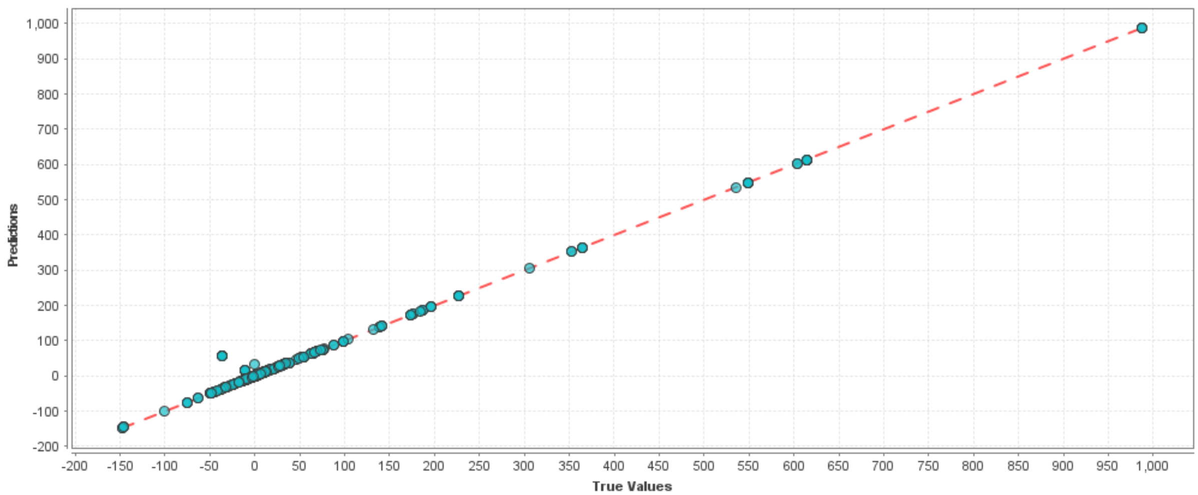


Fig. 4.39: COMET-Farm Orchard/Vineyard Crop Support Vector Machine Predictions Chart

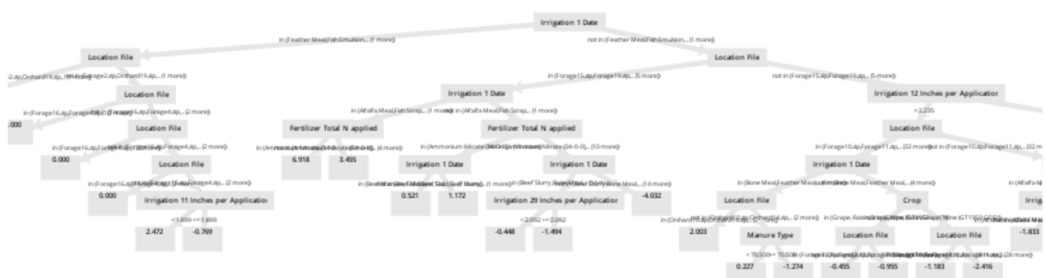


Fig. 4.40: COMET-Farm Orchard/Vineyard Crop Gradient Boosted Tree

Fig. 4.41: COMET-Farm Orchard/Vineyard Crop Decision Tree

worst performance. Figure 4.77 and Figure 4.65 shows Predictions Chart for Deep Learning and Random Forest respectively. We can notice the deflected predicted values from actual values in the figures. Gradient Boosted tree Predictions Chart which is shown in Figure 4.63 shows that there are t43 outliers. The relative error is 2%. Decision tree Predictions

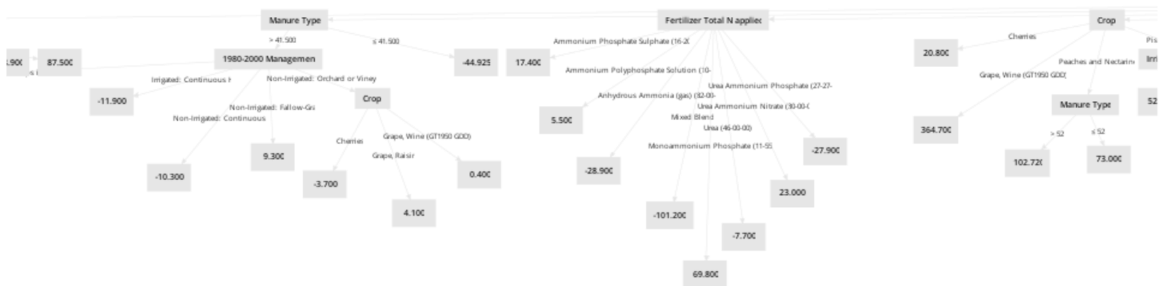


Fig. 4.42: COMET-Farm Orchard/Vineyard Crop Decision Tree Part 1

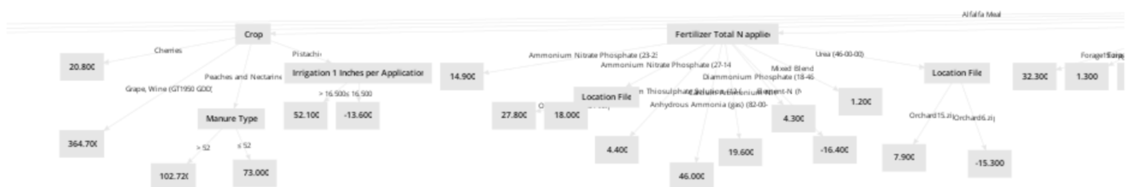


Fig. 4.43: COMET-Farm Orchard/Vineyard Crop Decision Tree Part 2

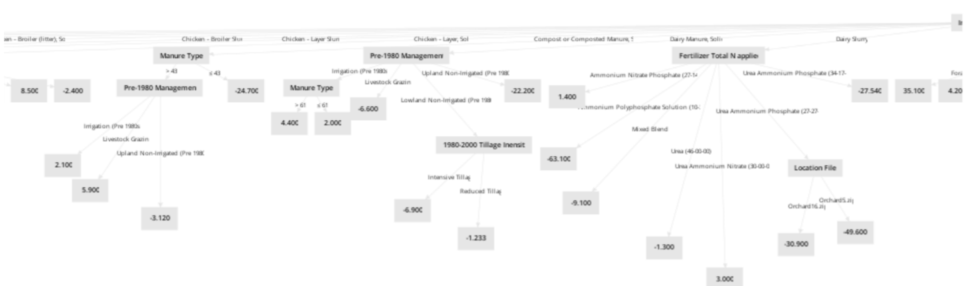


Fig. 4.44: COMET-Farm Orchard/Vineyard Crop Decision Tree Part 3

Chart is shown in Figure 4.64 with relative error of 5%. Support Vector Machine and Gradient Boosted Tree Model performed very well in this case with 2% and 3% relative error. Gradient Boosted tree generates 100's of trees for showing relationship between the input attributes. Figure 4.68 shows one of the tees from the results. Decision tree generates a single tree which shows how all the attributes affect the result is shown in Figure 4.69. It is a big tree so for closer look we have shown this tree in different parts which is shown in Figure 4.70, Figure 4.71, Figure 4.72, and Figure 4.73. The best model for this dataset is

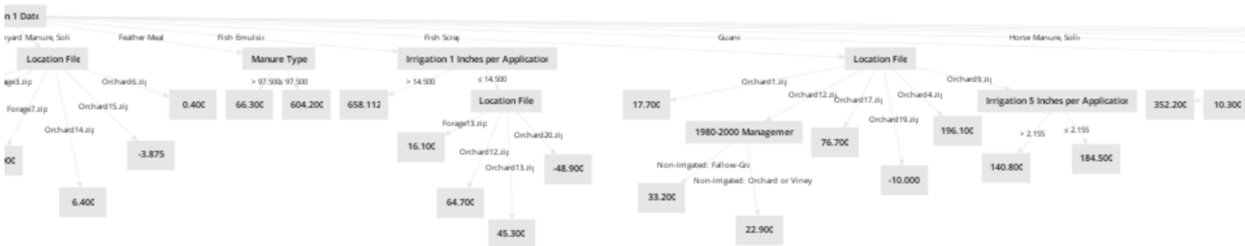


Fig. 4.45: COMET-Farm Orchard/Vineyard Crop Decision Tree Part 4

Attribute	Weight
Irrigation 1 Date = Fish Emulsion	0.456
Location File = Forage2.zip	0.299
Irrigation 1 Inches per Application	0.263
Location File = Orchard19.zip	0.247
Crop = Peaches and Nectarines	0.216
Irrigation 1 Date = Soybean Meal	0.208
Irrigation 5 Inches per Application	0.198
Crop = Cherries	0.180
Crop = Pistachio	0.174
Irrigation 26 Inches per Application	0.174
Location File = Orchard20.zip	0.161
Fertilizer Total N applied = Diammonium Phosphate (18-46-00)	0.159
Fertilizer Total N applied = Anhydrous Ammonia (gas) (82-00-00)	0.143
Fertilizer Total N applied = Mixed Blends	0.127
Irrigation 1 Date = Swine Manure, Slurry	0.119
Irrigation 1 Date = Dairy Slurry	0.109
Pre-1980 Management = Livestock Grazing	0.109
Irrigation 1 Date = Alfalfa Meal	0.105
Irrigation 1 Date = Chicken - Broiler Slurry	0.101
Irrigation 8 Inches per Application	0.099
Irrigation 27 Inches per Application	0.099
Irrigation 2 Inches per Application	0.099
1980-2000 Management = Non-Irrigated: Livestock Grazing	0.097
Fertilizer Total N applied = Calcium Nitrate	0.096
Crop = Grape, Wine (GT1950 GDD)	0.096
Irrigation 1 Date = Beef Manure, Solid	0.094
Irrigation 1 Date = Bone Meal	0.092
Fertilizer Total N applied = Urea Ammonium Phosphate (34-17-00)	0.090
Location File = Forage8.zip	0.087
Irrigation 6 Inches per Application	0.086
Irrigation 1 Date = Guano	0.084
Irrigation 1 Date = Sheep Manure, Solid	0.083
Irrigation 9 Inches per Application	0.083
Irrigation 24 Inches per Application	0.081

Attribute	Weight
1980-2000 Management = Non-Irrigated: Fallow-Grain	0.067
Location File = Orchard6.zip	0.066
Irrigation 1 Date = Chicken - Layer, Solid	0.066
Irrigation 1 Date = Swine Manure, Solid	0.064
1980-2000 Management = Irrigated: Annual Crops with Hay/Pasture in Rotation	0.064
Irrigation 1 Date = Farmyard Manure, Solid	0.062
Irrigation 23 Inches per Application	0.062
Location File = Forage19.zip	0.062
Location File = Orchard10.zip	0.062
Location File = Orchard3.zip	0.060
Location File = Orchard4.zip	0.058
Fertilizer Total N applied = Urea (46-00-00)	0.057
Irrigation 3 Inches per Application	0.057
Irrigation 1 Date = Chicken - Broiler (litter), Solid	0.055
Irrigation 1 Date = Horse Manure, Solid	0.053
Fertilizer Total N applied = Ammonium Phosphate Sulphate (16-20-00)	0.053
Location File = Orchard16.zip	0.053
Location File = Forage4.zip	0.053
Irrigation 30 Inches per Application	0.050
Location File = Orchard5.zip	0.049
1980-2000 Management = Non-Irrigated: Continuous Hay	0.049
Irrigation 31 Inches per Application	0.048
Location File = Forage10.zip	0.048
Location File = Forage7.zip	0.046
Irrigation 14 Inches per Application	0.044
Fertilizer Total N applied = Ammonium Nitrate (34-0-0)	0.043
Location File = Forage18.zip	0.042
Irrigation 25 Inches per Application	0.042
Irrigation 19 Inches per Application	0.041
1980-2000 Tillage Inensity = No Till	0.041
Fertilizer Total N applied = Ammonium Sulphate (21-00-00)	0.040
Location File = Forage15.zip	0.040
Location File = Forage20.zip	0.040
Fertilizer Total N applied = Ammonium Polyphosphate Solution (10-34-00)	0.039
Fertilizer Total N applied = Calcium Ammonium Nitrate	0.039
Location File = Orchard11.zip	0.038
Irrigation 1 Date = Chicken - Layer Slurry	0.037
Irrigation 32 Inches per Application	0.036
Location File = Forage13.zip	0.035
Location File = Orchard1.zip	0.035
Location File = Forage11.zip	0.035
Irrigation 22 Inches per Application	0.033
Irrigation 28 Inches per Application	0.033
Location File = Orchard13.zip	0.032
Irrigation 11 Inches per Application	0.032
Pre-1980 Management = Lowland Non-Irrigated (Pre 1980s)	0.031
Location File = Forage3.zip	0.031
1980-2000 Tillage Inensity = Reduced Tillage	0.029

Attribute	Weight
1980-2000 Management = Non-Irrigated: Annual Crops in Rotation	0.029
Irrigation 13 Inches per Application	0.027
Location File = Orchard12.zip	0.027
Location File = Orchard9.zip	0.027
Manure Type	0.027
Location File = Orchard18.zip	0.027
Location File = Forage17.zip	0.026
Fertilizer Total N applied = Ammonium Nitrate Phosphate (27-14-00)	0.025
Fertilizer Total N applied = Urea Ammonium Nitrate (30-00-00)	0.025
1980-2000 Management = Non-Irrigated: Orchard or Vineyard	0.025
Location File = Orchard14.zip	0.025
Irrigation 17 Inches per Application	0.024
Irrigation 29 Inches per Application	0.022
Location File = Forage14.zip	0.022
Location File = Forage12.zip	0.020
Location File = Orchard17.zip	0.019
Irrigation 20 Inches per Application	0.018
Fertilizer Total N applied = Ammonium Nitrate Phosphate (23-23-00)	0.018
Irrigation 7 Inches per Application	0.015
Crop = Grape, Raisin	0.015
Irrigation 12 Inches per Application	0.012

Fig. 4.46: COMET-Farm Orchard/Vineyard Crop Attribute Weights

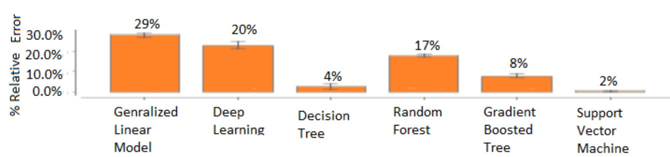


Fig. 4.47: COMET-Farm Annual Crop Regression Models Relative error Overview

Support Vector Machine Model with 2% relative error.

4.3.3 COMET-Farm Animal Agriculture Results

Though there are four different types of animals Heifers Stockers, Steers Stocker, Feedlot Cattle and Dairy-Lactating Cow we combined Heifer and Steer Stocker data in one dataset as they share the similar inputs.

For COMET-Farm Stockers we have trained model with 1500 runs data. This dataset has 33 attributes. Figure 4.75 shows relative error for all the models after training. Predictions Chart of Generalized Linear Model and Deep Learning is shown in Figure 4.76 and Figure 4.77. Relative error for Generalized Linear model prediction is 28% and for

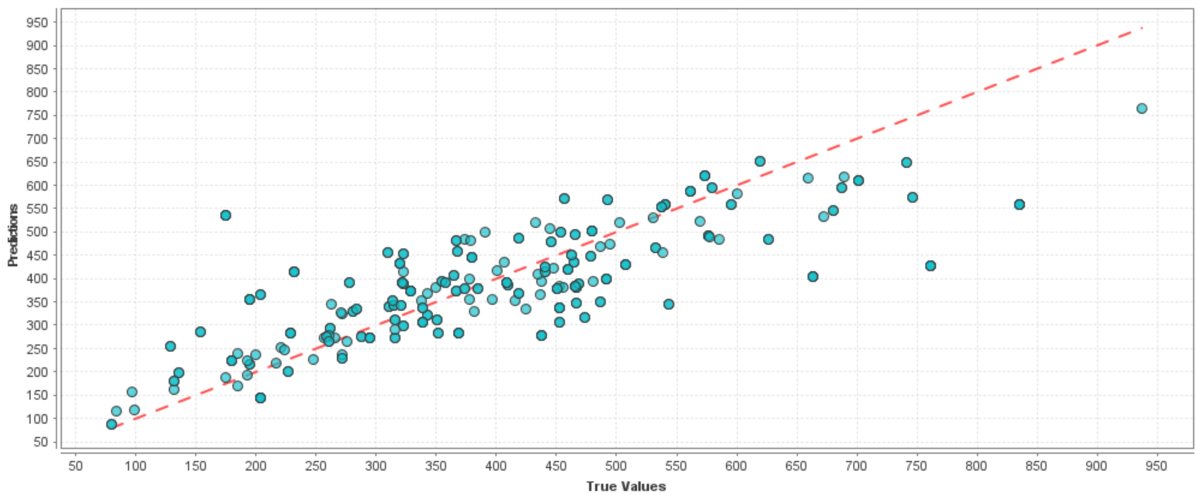


Fig. 4.48: COMET-Farm Annual Crop Generalized Linear Model Predictions Chart

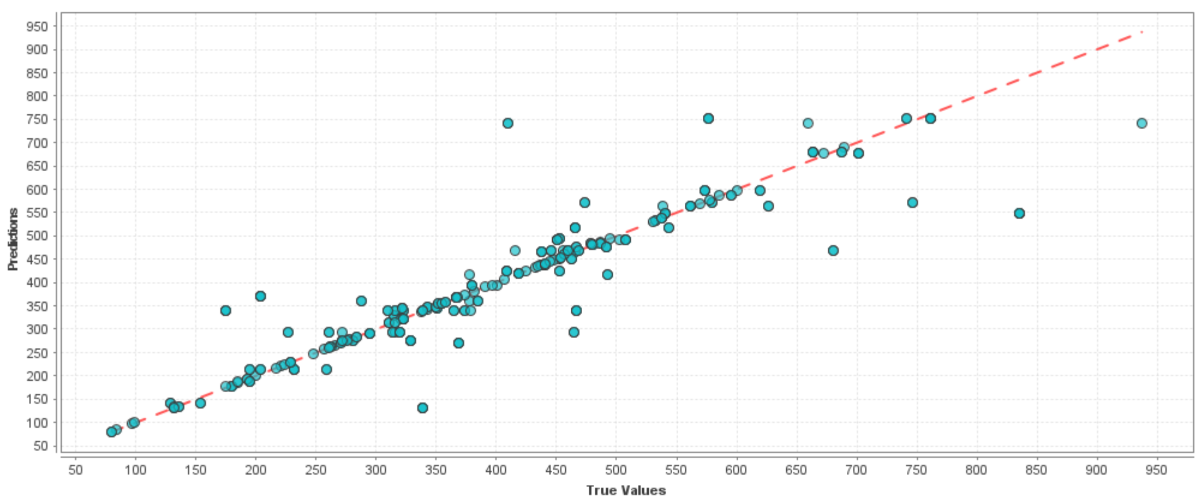


Fig. 4.49: COMET-Farm Annual Crop Deep Learning Predictions Chart

Deep Learning its 27%. We can notice many outline in both the cases. Figure 4.79 shows Predictions Chart for Random Forest Model with 14% relative error.

Gradient Boosted Tree model gives a relative error of 2% and its Prediction chart is shown in Figure 4.80. It also generated several trees which shows attribute dependencies and relationship one of these trees is shown in Figure 4.82. Figure 4.78 shows the Predictions Chart for Decision Tree. Decision tree also generated a Decision Tree shown in Figure 4.83. For closer look we are showing this tree in different parts in , Figure 4.85, Figure 4.86, Figure 4.87, Figure 4.88, and Figure 4.89.

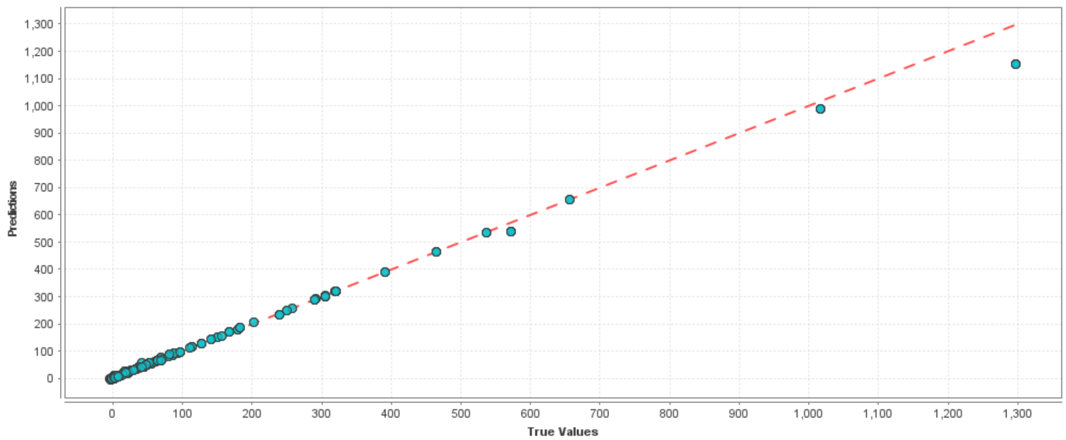


Fig. 4.50: COMET-Farm Annual Crop Decision Tree Predictions Chart

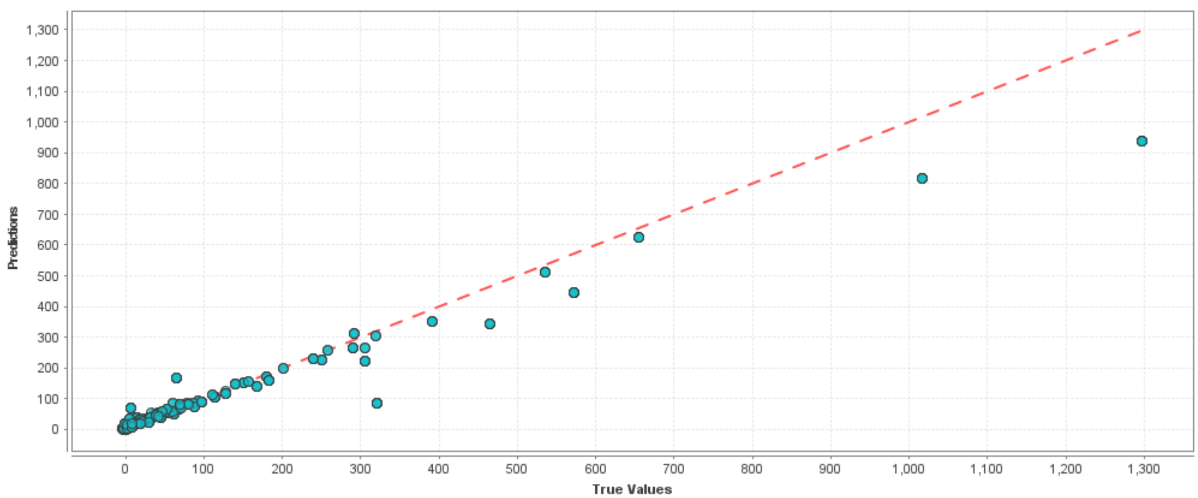


Fig. 4.51: COMET-Farm Annual Crop Random Forest Predictions Chart

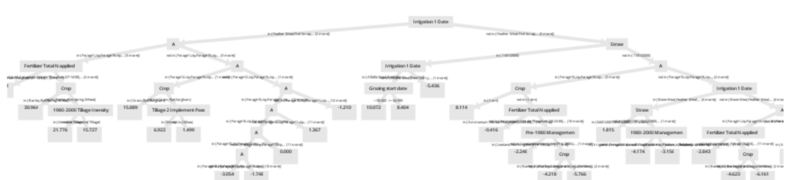


Fig. 4.52: COMET-Farm Annual Crop Gradient Boosted Tree

The best model for this dataset is Gradient Boosted Tree model and Support vector Machine Model both with 2% relative error. Attributes weight table shown in Figure 4.90. From this table we can say that Stockers count is highly affecting the results. And Liquid

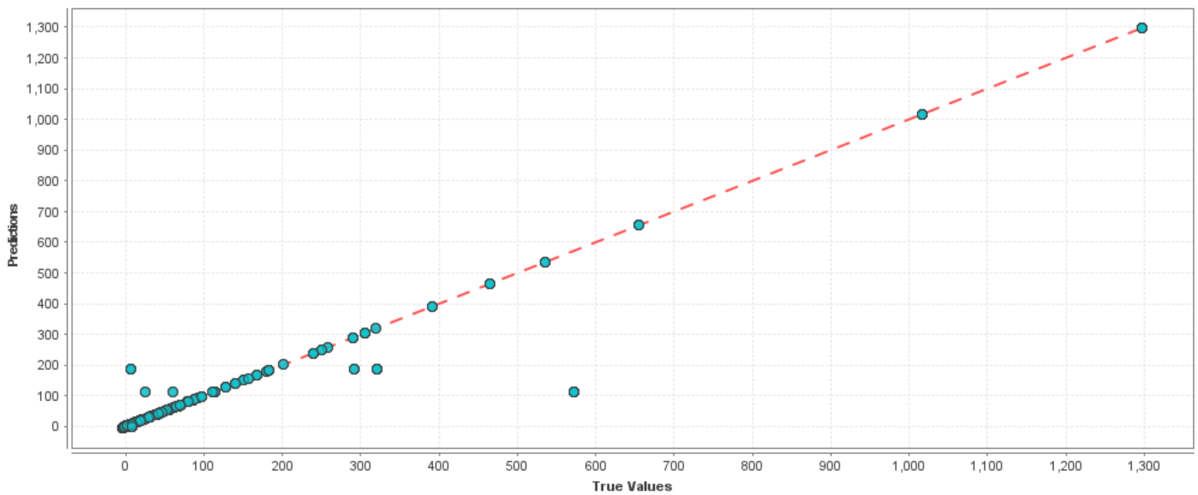


Fig. 4.53: COMET-Farm Annual Crop Gradient Boosted Tree Predictions Chart

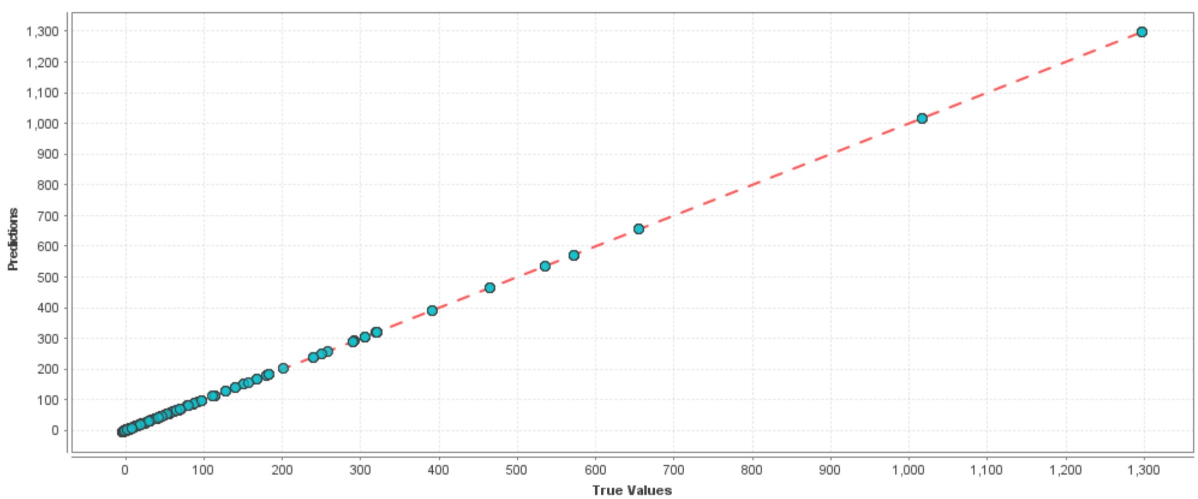


Fig. 4.54: COMET-Farm Annual Crop Support Vector Machine Predictions Chart

Fig. 4.55: COMET-Farm Annual Crop Decision Tree

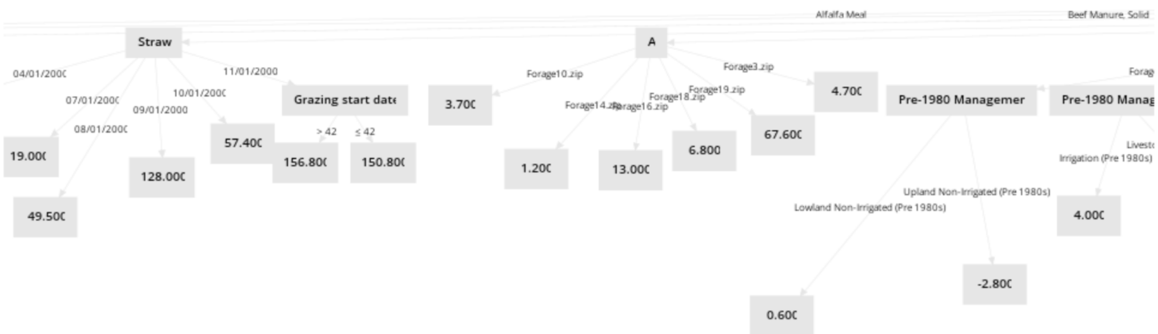


Fig. 4.56: COMET-Farm Annual Crop Decision Tree Part 1

Fig. 4.57: COMET-Farm Annual Crop Decision Tree Part 2

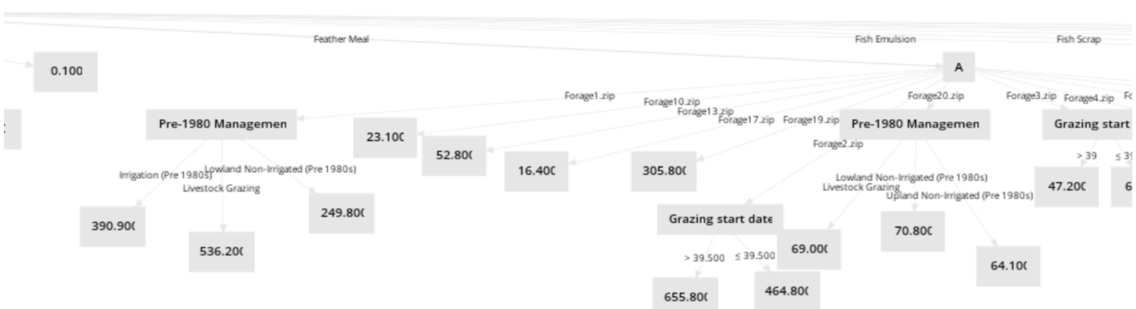


Fig. 4.58: COMET-Farm Annual Crop Decision Tree Part 3

Treatment Method Aerobic Lagoon and Storage Method Aerobic Lagoon has high impact on results in comparison to other methods.

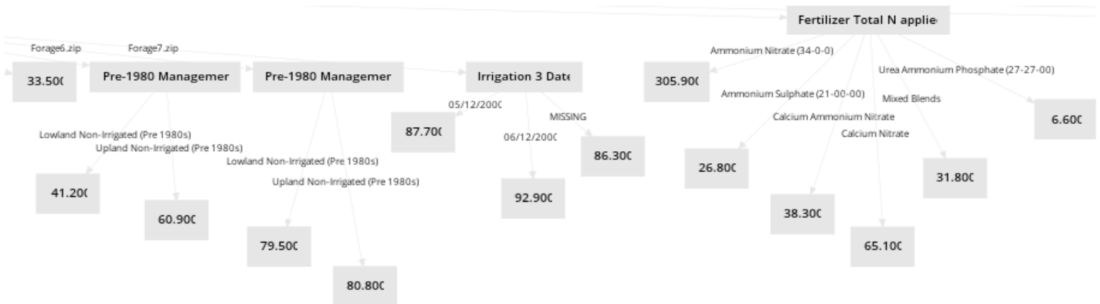


Fig. 4.59: COMET-Farm Annual Crop Decision Tree Part 4

Attribute	Weight
Irrigation 1 Date = Fish Scrap	0.355
Irrigation 1 Date = Guano	0.266
Fertilizer Total N applied = Ammonium Nitrate Phosphate (27-14-00)	0.261
Irrigation 1 Inches per Application	0.247
A = Forage8.zip	0.228
Fertilizer Total N applied = Calcium Nitrate	0.223
Irrigation 1 Date = Feather Meal	0.207
A = Forage9.zip	0.207
A = Forage1.zip	0.170
Crop = Alfalfa	0.139
Manure Type	0.139
A = Forage17.zip	0.129
1980-2000 Management = Non-Irrigated: Orchard or Vineyard	0.129
Fertilizer Total N applied = Monoammonium Phosphate (12-51-00)	0.124
Irrigation 8 Date = MISSING	0.119
Irrigation 7 Date = MISSING	0.119
A = Forage2.zip	0.116
Irrigation 1 Date = Soybean Meal	0.113
Irrigation 1 Date = Chicken - Broiler Slurry	0.112
Pre-1980 Management = Upland Non-Irrigated (Pre 1980s)	0.103
A = Forage10.zip	0.101
Fertilizer Total N applied = Calcium Ammonium Nitrate	0.099
Crop = Corn Silage	0.098
A = Forage18.zip	0.097
1980-2000 Management = Irrigated: Annual Crops with Hay/Pasture in Rotation	0.096
Crop = Grass	0.096
Irrigation 1 Date = Swine Manure, Slurry	0.092
Grazing start date	0.091
Grazing end date	0.091
Irrigation 1 Date = Chicken - Layer, Solid	0.089
1980-2000 Management = Irrigated: Continuous Hay	0.088
Irrigation 1 Date = Chicken - Layer Slurry	0.086
Irrigation 1 Date = Beef Manure, Solid	0.085
A = Forage4.zip	0.083
Straw = 08/01/2000	0.081

Attribute	Weight
A = Forage5.zip	0.072
Fertilizer Total N applied = Ammonium Sulphate (21-00-00)	0.072
Irrigation 1 Date = Swine Manure, Solid	0.072
1980-2000 Management = Non-Irrigated: Annual Crops in Rotation	0.070
Irrigation 1 Date = Horse Manure, Solid	0.070
Irrigation 1 Date = Beef Slurry	0.069
Irrigation 1 Date = Sheep Manure, Solid	0.067
A = Forage14.zip	0.066
Fertilizer Total N applied = Ammonium Thiosulphate Solution (12-00-00)	0.066
A = Forage3.zip	0.065
A = Forage6.zip	0.065
Manure Amount applied = 05/14/2000	0.064
Manure date = 06/15/2000	0.064
A = Forage11.zip	0.063
Fertilizer Total N applied = Urea Ammonium Phosphate (27-27-00)	0.063
Fertilizer Total N applied = Mixed Blends	0.063
Planting date = 06/01/2000	0.063
Irrigation 8 Date = 07/06/2000	0.062
Irrigation 7 Date = 06/25/2000	0.062
Irrigation 6 Date = 06/14/2000	0.062
Irrigation 5 Date = 06/01/2000	0.062
Irrigation 4 Date = 05/23/2000	0.062
Irrigation 3 Date = 05/12/2000	0.062
A = Forage15.zip	0.062
A = Forage16.zip	0.062
Fertilizer Total N applied = Element-N (N)	0.060
A = Forage19.zip	0.059
Crop = Barley	0.057
Irrigation 2 Date = 05/01/2000	0.055
Fertilizer Total N applied = Diammonium Phosphate (18-46-00)	0.053
Fertilizer Total N applied = Ammonium Phosphate Sulphate (16-20-00)	0.052
Straw = 04/01/2000	0.052
Crop = Rye	0.050
Tillage 2 Implement Pass = No Tillage	0.047
Manure Amount applied = 09/15/2000	0.046
Manure date = 01/01/2000	0.046
Planting date = 10/01/2000	0.046
Fertilizer Total N applied = Monoammonium Phosphate (11-55-00)	0.044
Pre-1980 Management = Lowland Non-Irrigated (Pre 1980s)	0.043
Fertilizer Total N applied = Potassium Nitrate	0.042
Fertilizer Total N applied = Urea (46-00-00)	0.040
1980-2000 Management = Irrigated: Annual Crops in Rotation	0.039
Manure Amount applied = 04/14/2000	0.037
Manure date = 05/14/2000	0.037
Planting date = 05/01/2000	0.037
1980-2000 Management = Non-Irrigated: Livestock Grazing	0.034
Irrigation 11 Date = 06/29/2000	0.031
Irrigation 10 Date = 06/22/2000	0.031

Attribute	Weight
Irrigation 10 Date = 06/22/2000	0.031
Irrigation 9 Date = 06/15/2000	0.031
Irrigation 8 Date = 06/08/2000	0.031
Irrigation 7 Date = 06/01/2000	0.031
Irrigation 6 Date = 05/29/2000	0.031
Irrigation 5 Date = 05/22/2000	0.031
Irrigation 4 Date = 05/15/2000	0.031
Irrigation 3 Date = 05/08/2000	0.031
Irrigation 3 Date = 05/08/2000	0.031
Fertilizer Total N applied = Urea Ammonium Phosphate (34-17-00)	0.030
Fertilizer Total N applied = Ammonium Nitrate Phosphate (23-23-00)	0.027
Irrigation 11 Date = 09/07/2000	0.026
Irrigation 10 Date = 08/27/2000	0.026
Irrigation 9 Date = 08/16/2000	0.026
Continue perennial crop from last year = No	0.025
Pre-1980 Management = Irrigation (Pre 1980s)	0.024
Irrigation 11 Date = 10/29/2000	0.024
Irrigation 10 Date = 10/22/2000	0.024
Irrigation 9 Date = 10/15/2000	0.024
1980-2000 Management = Non-Irrigated: Continuous Hay	0.023
Irrigation 11 Date = 08/08/2000	0.019
Irrigation 10 Date = 07/28/2000	0.019
Irrigation 9 Date = 07/17/2000	0.019
1980-2000 Tillage Inensity = No Till	0.018
Fertilizer Total N applied = Ammonium Polyphosphate Solution (10-34-00)	0.017
Fertilizer Total N applied = Urea Ammonium Nitrate (30-00-00)	0.016
A = Forage12.zip	0.014
Tillage 2 Implement Pass = Mow	0.013
Straw = 09/01/2000	0.012
Irrigation 11 Date = 11/29/2000	0.012
Irrigation 10 Date = 11/22/2000	0.012
Irrigation 9 Date = 11/15/2000	0.012

Fig. 4.60: COMET-Farm Annual Crop Attribute Weights

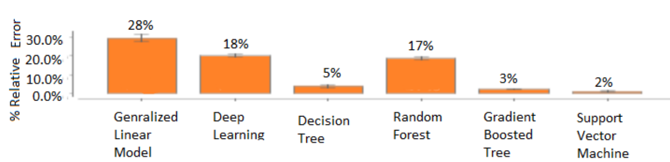


Fig. 4.61: COMET-Farm Seasonal Crop Regression Models Relative error Overview

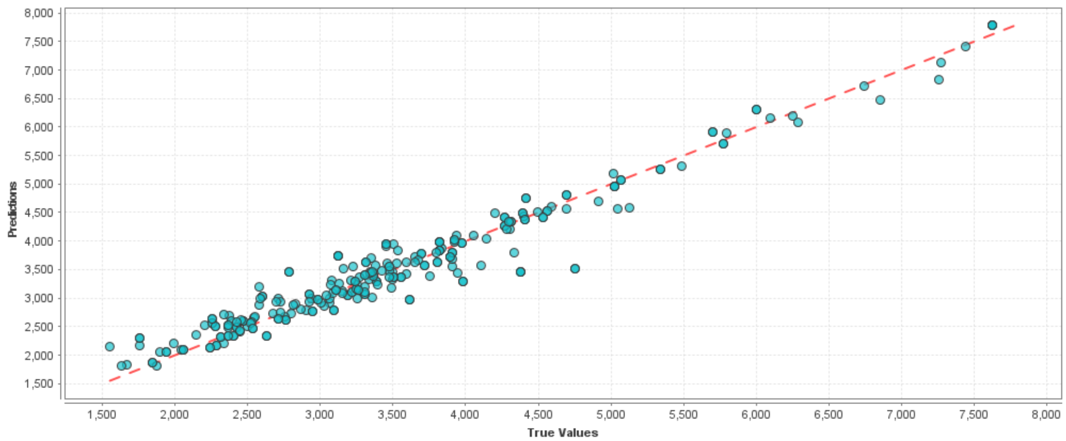


Fig. 4.62: COMET-Farm Seasonal Crop Generalized Linear Model Predictions Chart

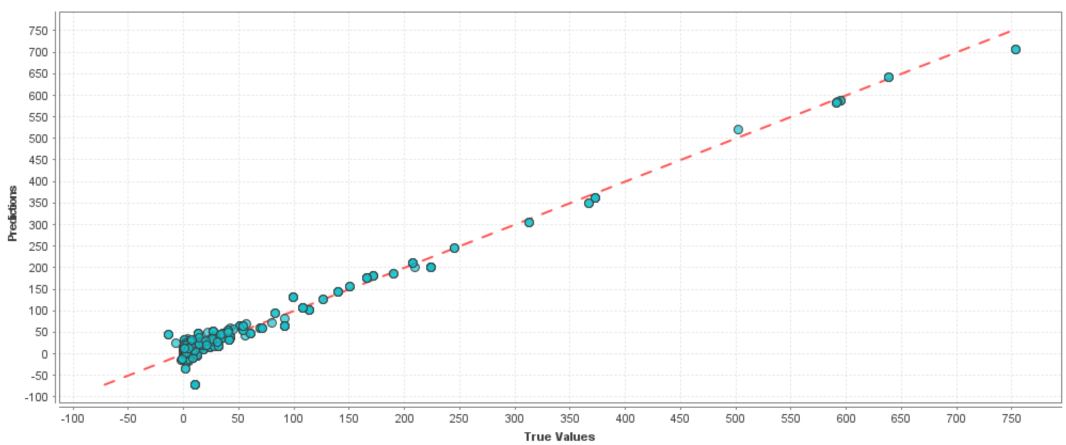


Fig. 4.63: COMET-Farm Seasonal Crop Deep Learning Predictions Chart

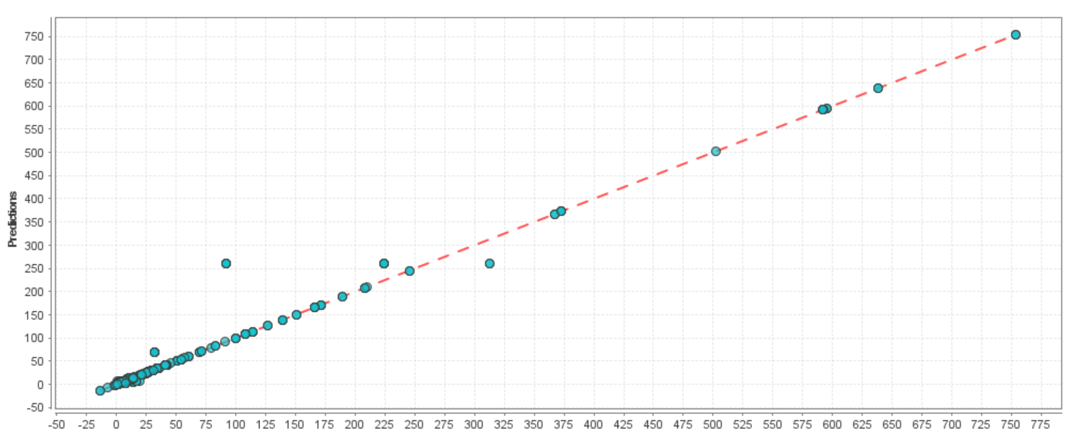


Fig. 4.64: COMET-Farm Seasonal Crop Decision Tree Predictions Chart

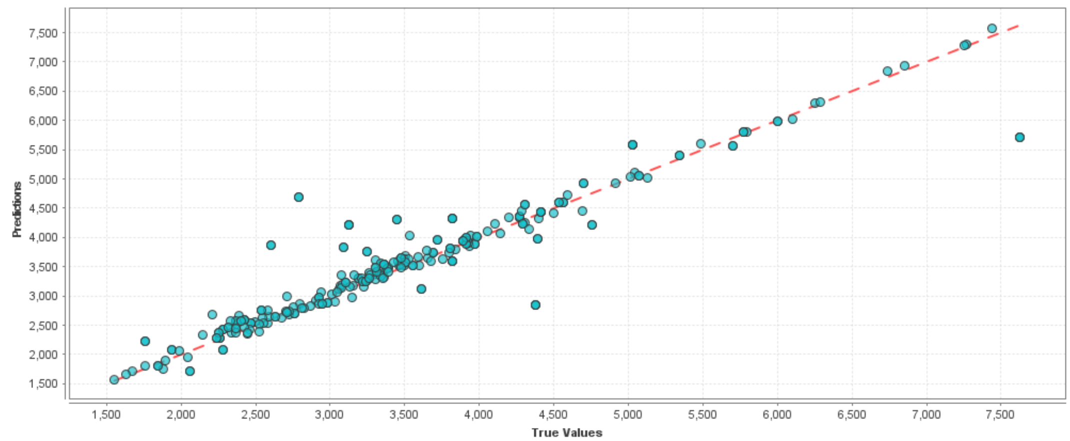


Fig. 4.65: COMET-Farm Seasonal Crop Random Forest Predictions Chart

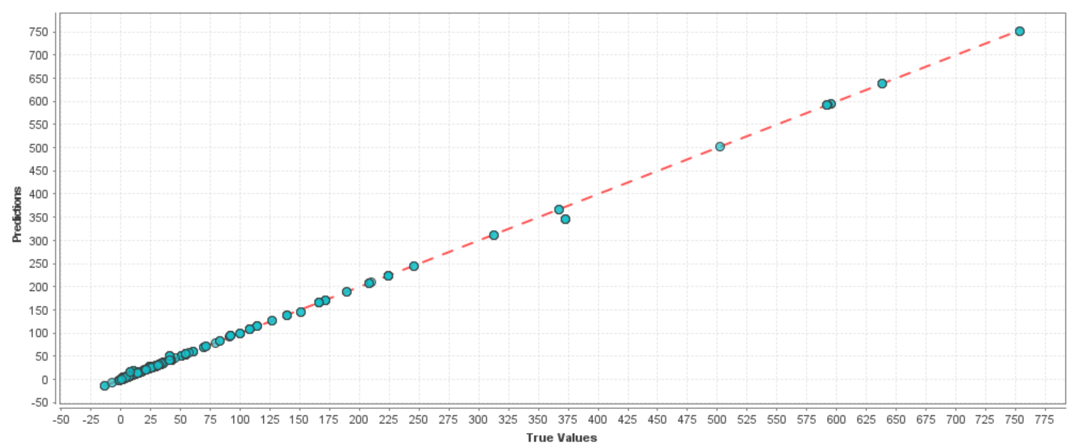


Fig. 4.66: COMET-Farm Seasonal Crop Gradient Boosted Tree Predictions Chart

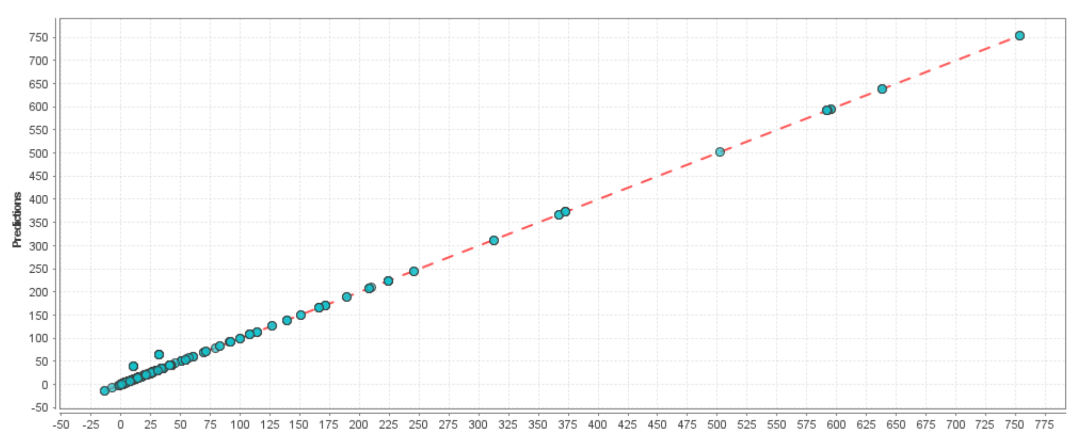


Fig. 4.67: COMET-Farm Seasonal Crop Support Vector Machine Predictions Chart

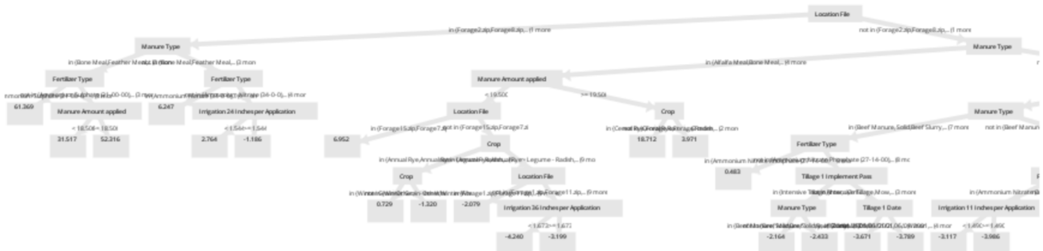


Fig. 4.68: COMET-Farm Seasonal Crop Gradient Boosted Tree

Fig. 4.69: COMET-Farm Seasonal Crop Decision Tree

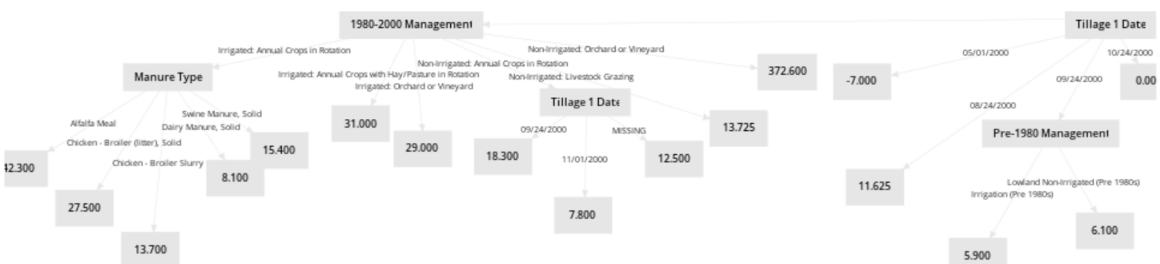


Fig. 4.70: COMET-Farm Seasonal Crop Decision Tree Part 1

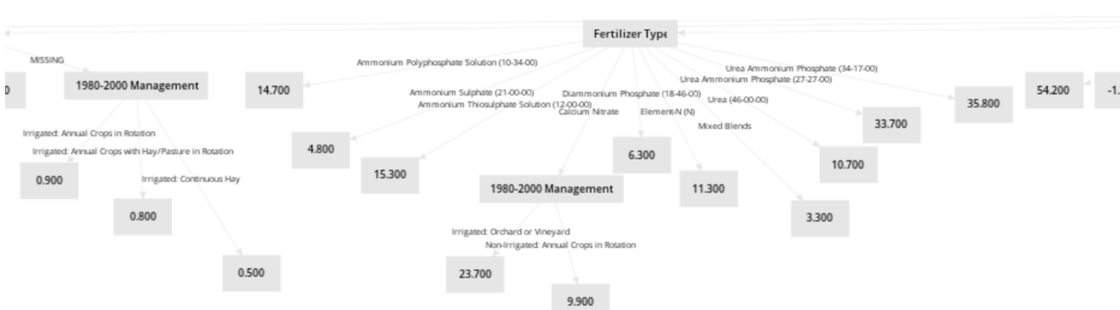


Fig. 4.71: COMET-Farm Seasonal Crop Decision Tree Part 2

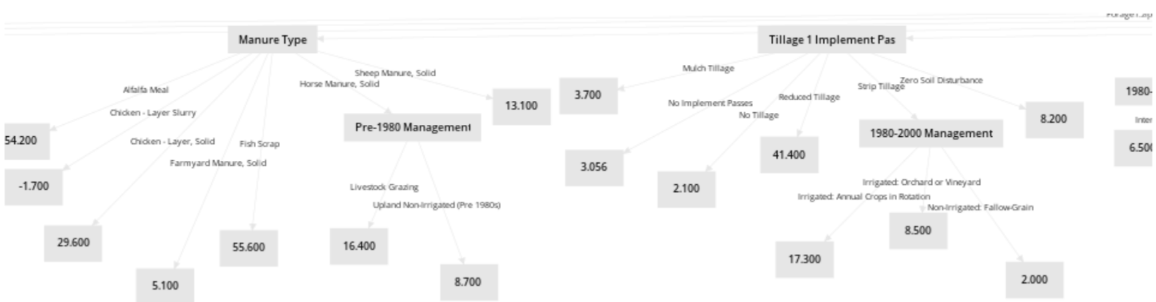


Fig. 4.72: COMET-Farm Seasonal Crop Decision Tree Part 3

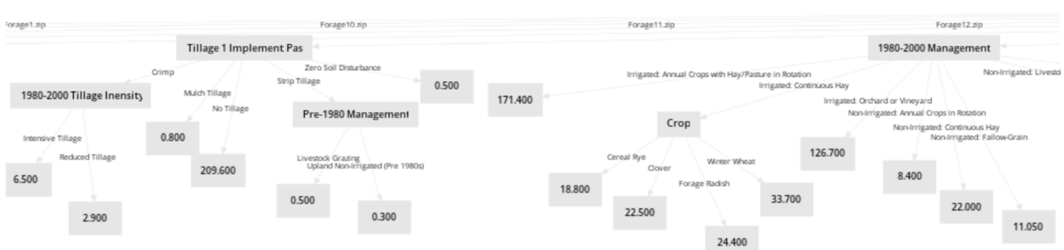


Fig. 4.73: COMET-Farm Seasonal Crop Decision Tree Part 4

Attribute	Weight
.ocation File = Forage8.zip	0.531
.ocation File = Forage9.zip	0.260
/lanure Type = Fish Scrap	0.254
/lanure Type = Bone Meal	0.224
›re-1980 Management = Irrigation (Pre 1980s)	0.184
.ocation File = Forage2.zip	0.177
I980-2000 Management = Non-Irrigated: Orchard or Vineyard	0.172
/lanure Type = Feather Meal	0.166
/lanure Type = Soybean Meal	0.163
'illage 1 Implement Pass = Intensive Tillage	0.158
/lanure Type = Fish Emulsion	0.150
/lanure Amount applied	0.146
'ertilizer Type = Anhydrous Ammonia (gas) (82-00-00)	0.140
rrigation 31 Inches per Application	0.139
rrigation 27 Inches per Application	0.137
›lanting date = 10/01/2000	0.135
rrigation 31 Date = 04/01/2001	0.130
rrigation 30 Date = 03/29/2001	0.130
rrigation 29 Date = 03/22/2001	0.130
rrigation 28 Date = 03/15/2001	0.130
rrigation 27 Date = 03/08/2001	0.130
/lanure date = 09/15/2000	0.130
rrigation 1 Date = 10/01/2000	0.130
rrigation 2 Date = 10/08/2000	0.130
rrigation 12 Date = 12/08/2000	0.130
rrigation 13 Date = 12/15/2000	0.130
rrigation 14 Date = 12/22/2000	0.130
rrigation 15 Date = 12/29/2000	0.130
rrigation 16 Date = 01/01/2001	0.130
rrigation 17 Date = 01/08/2001	0.130
rrigation 18 Date = 01/15/2001	0.130
rrigation 19 Date = 01/22/2001	0.130
rrigation 20 Date = 01/29/2001	0.130
rrigation 21 Date = 02/01/2001	0.130

Attribute	Weight
Irrigation 5 Date = MISSING	0.098
Manure Type = Chicken - Broiler Slurry	0.098
Tillage 1 Implement Pass = No Implement Passes	0.098
Fertilizer Date = 11/16/2000	0.096
Manure date = 10/14/2000	0.096
Irrigation 1 Date = 11/01/2000	0.096
Irrigation 2 Date = 11/08/2000	0.096
Irrigation 3 Date = 11/15/2000	0.096
Irrigation 4 Date = 11/22/2000	0.096
Irrigation 6 Date = 12/01/2000	0.096
Irrigation 7 Date = 12/08/2000	0.096
Irrigation 8 Date = 12/15/2000	0.096
Irrigation 9 Date = 12/22/2000	0.096
Irrigation 10 Date = 12/29/2000	0.096
Irrigation 11 Date = 01/01/2001	0.096
Irrigation 12 Date = 01/08/2001	0.096
Irrigation 13 Date = 01/15/2001	0.096
Irrigation 14 Date = 01/22/2001	0.096
Irrigation 15 Date = 01/29/2001	0.096
Irrigation 16 Date = 02/01/2001	0.096
Irrigation 17 Date = 02/08/2001	0.096
Irrigation 18 Date = 02/15/2001	0.096
Irrigation 19 Date = 02/22/2001	0.096
Irrigation 20 Date = 02/29/2001	0.096
Irrigation 21 Date = 03/01/2001	0.096
Irrigation 22 Date = 03/08/2001	0.096
Irrigation 23 Date = 03/15/2001	0.096
Irrigation 24 Date = 03/22/2001	0.096
Irrigation 25 Date = 03/29/2001	0.096
Irrigation 26 Date = 04/01/2001	0.096
Manure Type = Dairy Slurry	0.095
Crop = Corn	0.093
Tillage 1 Date = 10/24/2000	0.093
Planting date = 11/01/2000	0.092
Location File = Forage5.zip	0.091
Crop = Winter Grain-Other	0.090
1980-2000 Management = Non-Irrigated: Livestock Grazing	0.090
Tillage 1 Implement Pass = Broadcast Seed	0.088
Manure Type = Dairy Manure, Solid	0.088
Location File = Forage17.zip	0.088
Location File = Forage20.zip	0.087
Irrigation 36 Date = 06/01/2001	0.087
Irrigation 35 Date = 05/29/2001	0.087
Irrigation 34 Date = 05/22/2001	0.087
Irrigation 33 Date = 05/15/2001	0.087
Irrigation 32 Date = 05/08/2001	0.087
Manure Type = Farmyard Manure, Solid	0.085
Location File = Forage10.zip	0.085

Attribute	Weight
Manure Type = Horse Manure, Solid	0.085
Tillage 1 Date = 10/01/2000	0.084
Manure Type = Swine Manure, Solid	0.083
Crop = Oilseed Radish	0.082
Fertilizer Date = 01/01/2000	0.081
Location File = Forage19.zip	0.081
Location File = Forage13.zip	0.081
Fertilizer Type = Urea (46-00-00)	0.080
Location File = Forage6.zip	0.079
Irrigation 20 Inches per Application	0.078
1980-2000 Management = Non-Irrigated: Annual Crops in Rotation	0.077
1980-2000 Management = Irrigated: Annual Crops in Rotation	0.077
Irrigation 5 Inches per Application	0.077
Irrigation 12 Inches per Application	0.076
Location File = Forage4.zip	0.076
Irrigation 21 Inches per Application	0.076
Manure Type = Chicken - Layer Slurry	0.074
Irrigation 6 Inches per Application	0.074
Crop = Clover	0.074
Fertilizer Type = Urea Ammonium Phosphate (34-17-00)	0.074
Crop = Annual Rye - Legume - Radish	0.074
Irrigation 31 Date = 05/01/2001	0.074
Irrigation 30 Date = 04/29/2001	0.074
Irrigation 27 Date = 04/08/2001	0.074
Irrigation 7 Inches per Application	0.074
Manure Type = Guano	0.073
Harvest date = 05/01/2001	0.073
Irrigation 32 Inches per Application	0.072
Irrigation 15 Inches per Application	0.072
Manure Type = Beef Manure, Solid	0.071
Fertilizer Type = Mixed Blends	0.071
Irrigation 3 Inches per Application	0.069
Location File = Forage11.zip	0.069
Location File = Forage18.zip	0.067
Irrigation 22 Inches per Application	0.066
1980-2000 Management = Irrigated: Orchard or Vineyard	0.066
Fertilizer Type = Calcium Nitrate	0.065
Fertilizer Type = Diammonium Phosphate (18-46-00)	0.065
Irrigation 24 Inches per Application	0.064

Fig. 4.74: COMET-Farm Seasonal Crop Attribute Weights

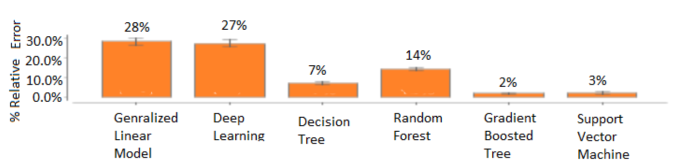


Fig. 4.75: COMET-Farm Stocker Regression Models Relative error Overview

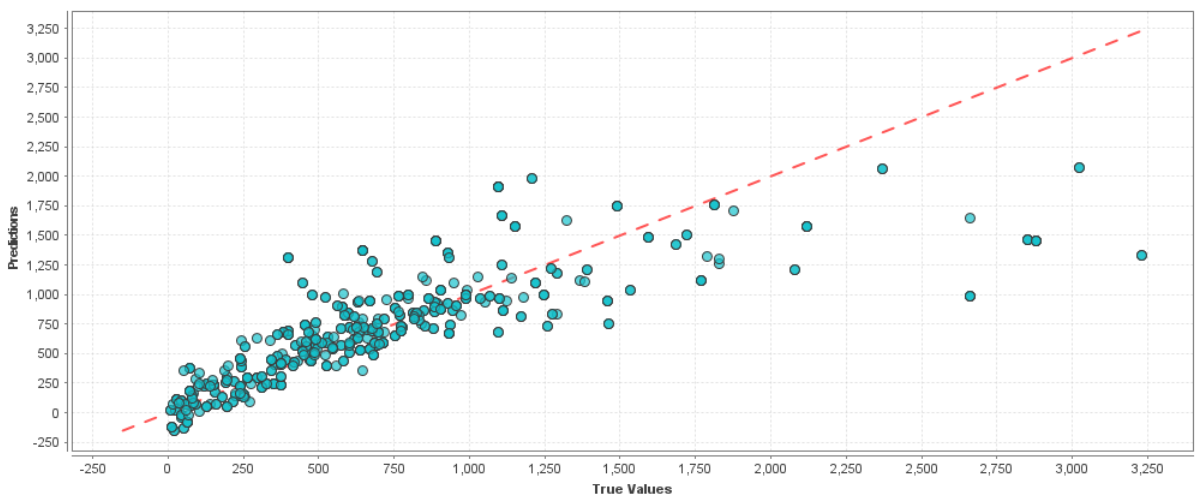


Fig. 4.76: COMET-Farm Stocker Crop Generalized Linear Model Predictions Chart

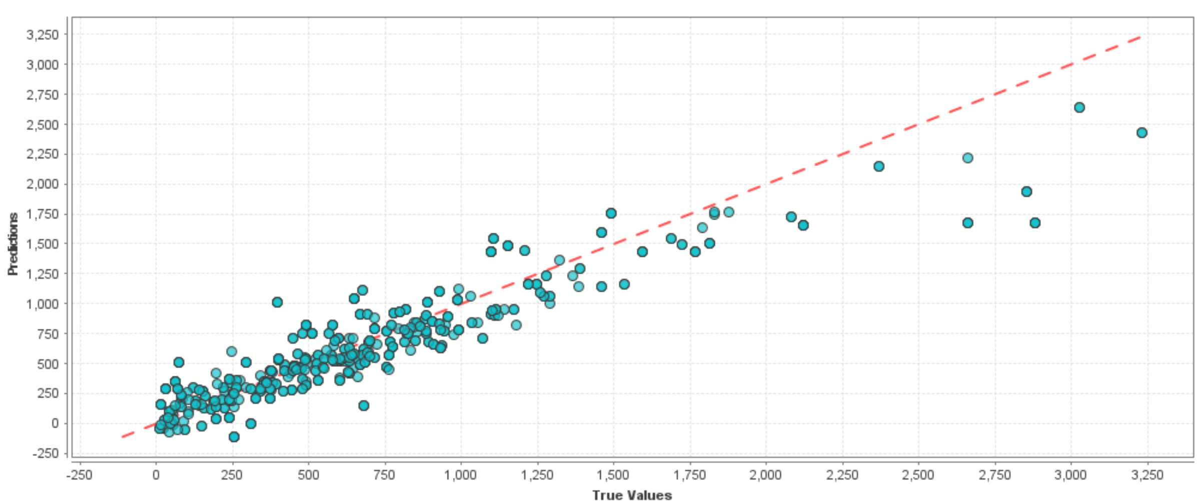


Fig. 4.77: COMET-Farm Stocker Deep Learning Predictions Chart

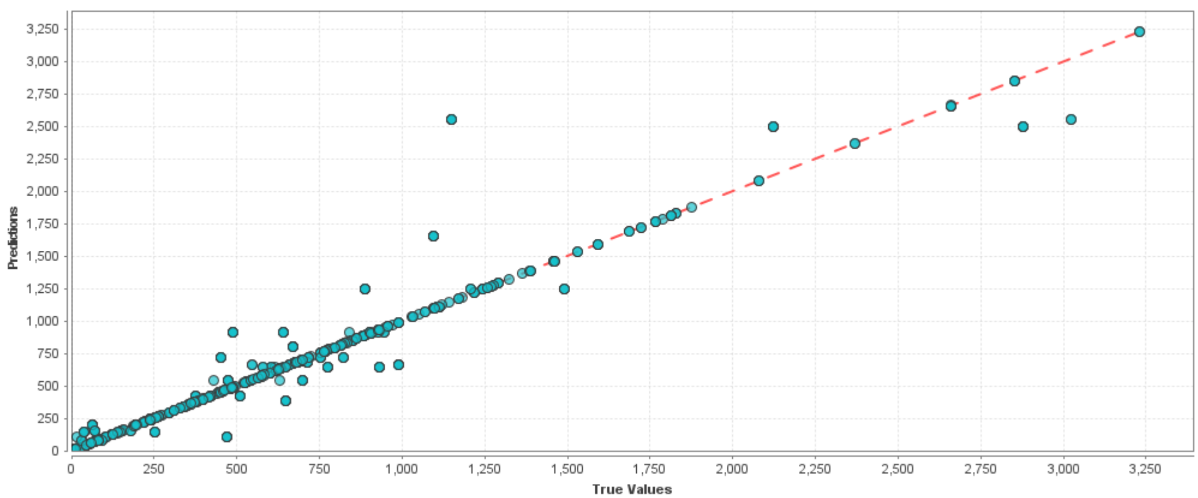


Fig. 4.78: COMET-Farm Stocker Decision Tree Predictions Chart

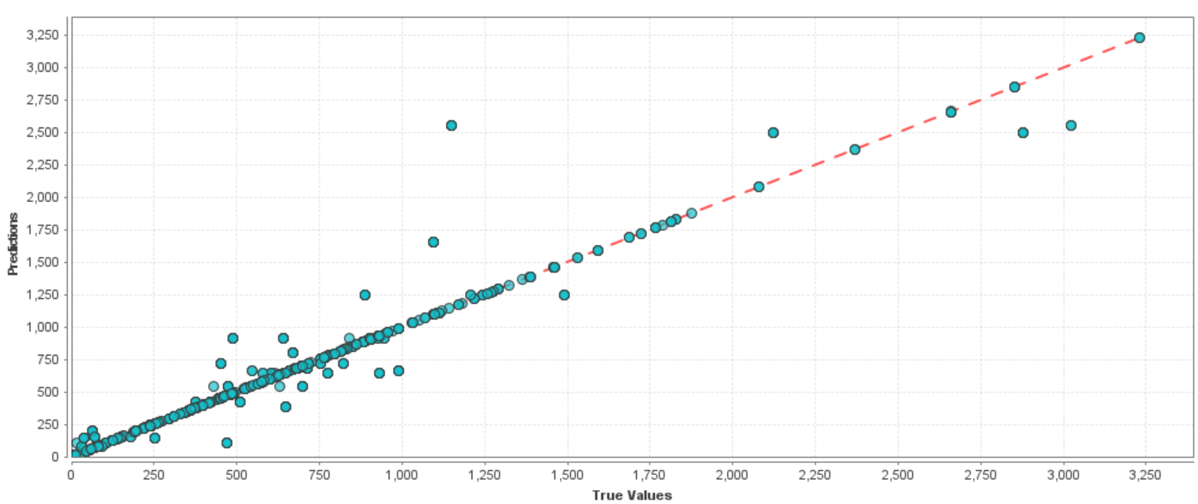


Fig. 4.79: COMET-Farm Stocker Random Forest Predictions Chart

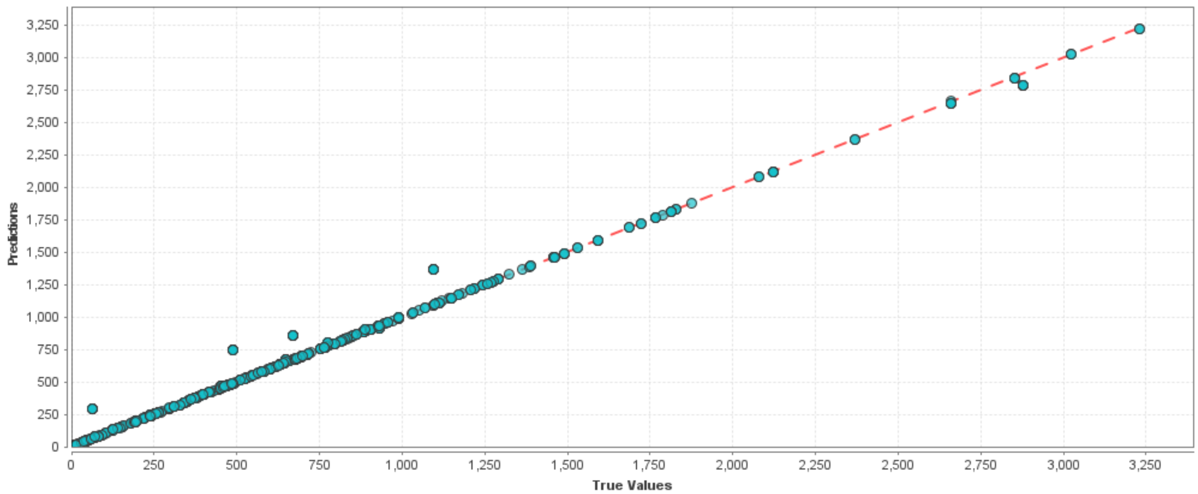


Fig. 4.80: COMET-Farm Stocker Gradient Boosted Tree Predictions Chart

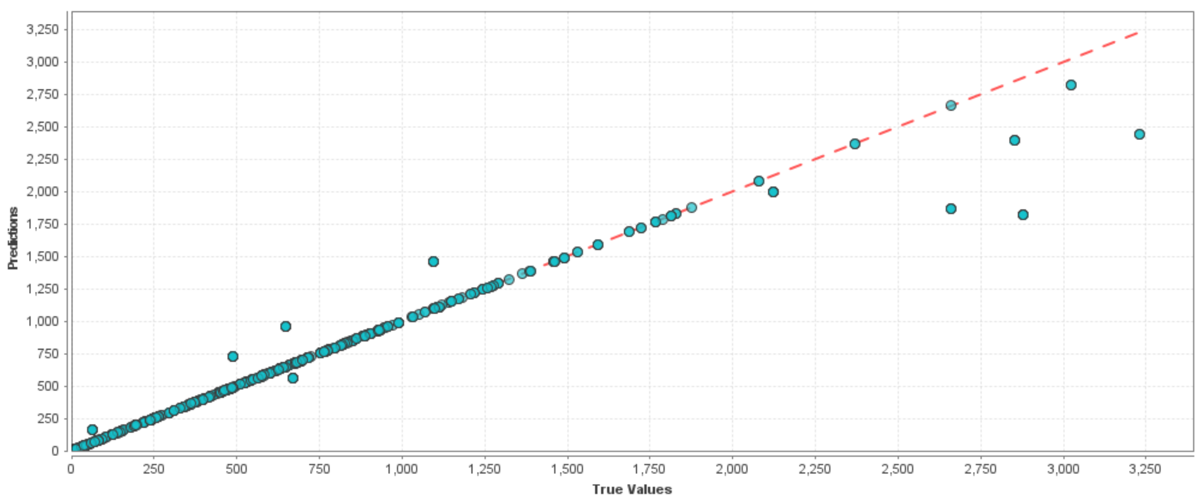


Fig. 4.81: COMET-Farm Stocker Support Vector Machine Predictions Chart

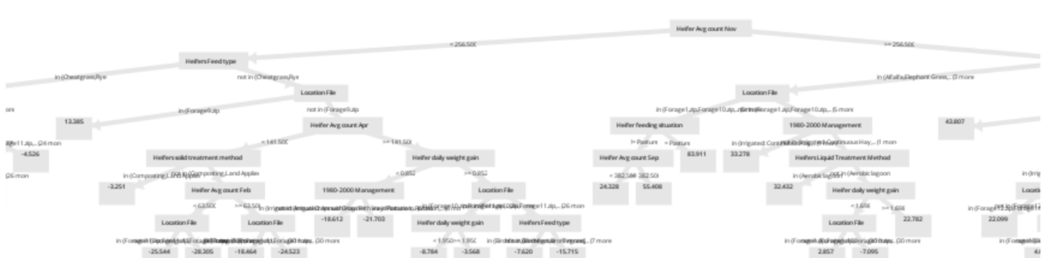


Fig. 4.82: COMET-Farm Stocker Gradient Boosted Tree

Fig. 4.83: COMET-Farm Stocker Decision Tree

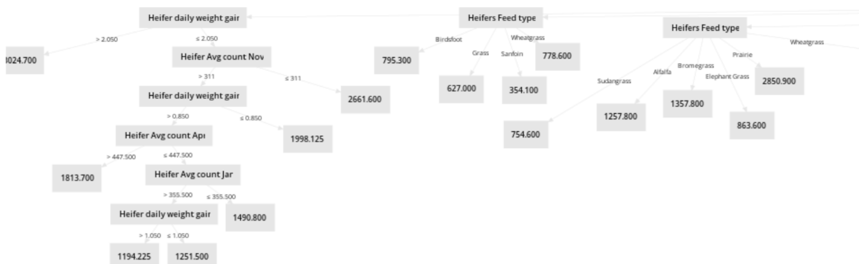


Fig. 4.84: COMET-Farm Stocker Decision Tree Part 1

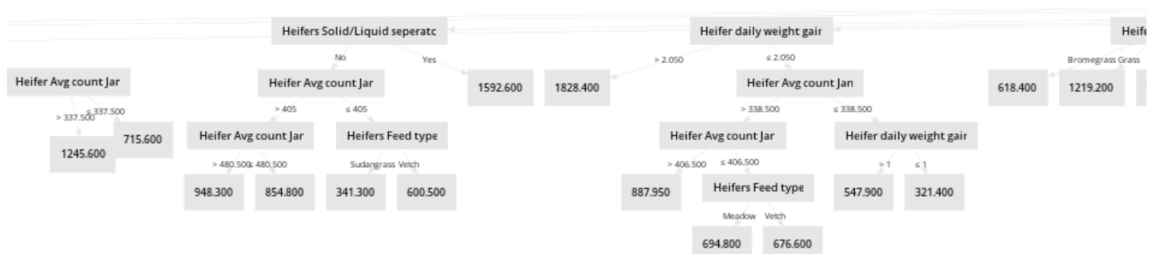


Fig. 4.85: COMET-Farm Stocker Decision Tree Part 2

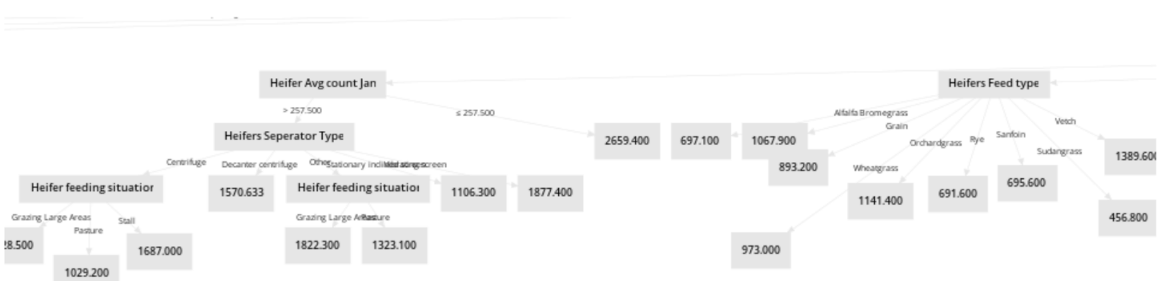


Fig. 4.86: COMET-Farm Stocker Decision Tree Part 3

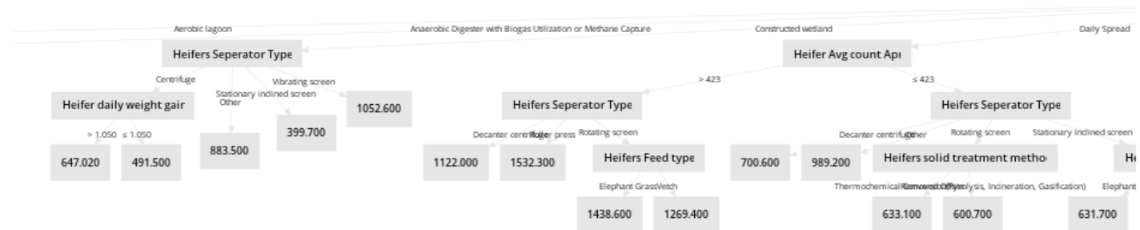


Fig. 4.87: COMET-Farm Stocker Decision Tree Part 4

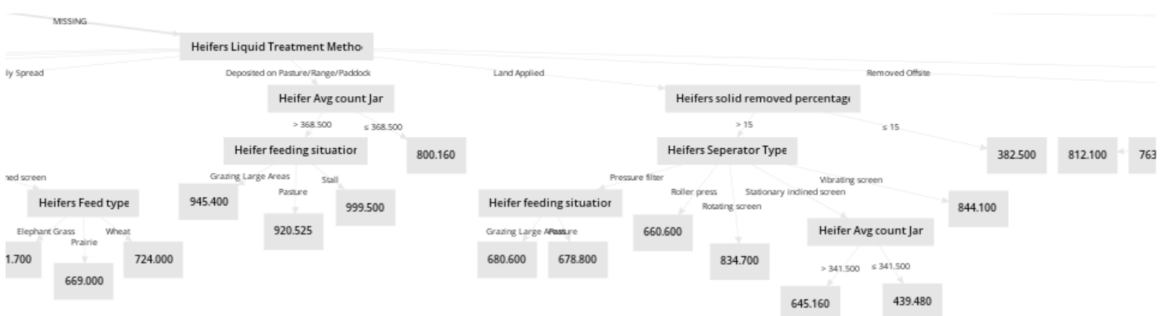


Fig. 4.88: COMET-Farm Stocker Decision Tree Part 5

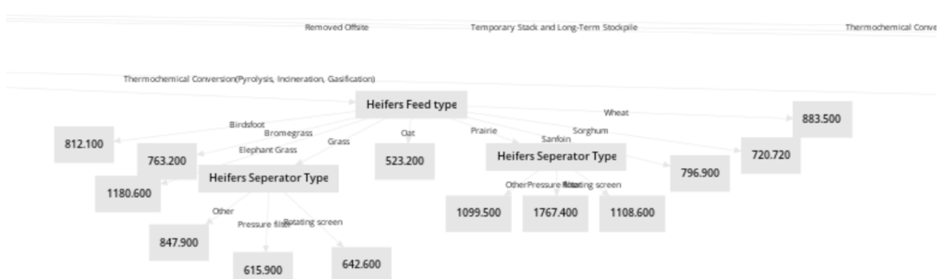


Fig. 4.89: COMET-Farm Stocker Decision Tree Part 6

Attribute	Weight
Heifer Avg count Sep	0.546
Heifer Avg count Aug	0.545
Heifer Avg count Feb	0.545
Heifer Avg count May	0.544
Heifer Avg count Jul	0.544
Heifer Avg count Nov	0.544
Heifer Avg count Mar	0.544
Heifer Avg count Jun	0.543
Heifer Avg count Apr	0.543
Heifer Avg count Oct	0.543
Heifer Avg count Dec	0.541
Heifers storage method = Aerobic lagoon	0.357
Heifers Liquid Treatment Method = Aerobic lagoon	0.344
Heifer daily weight gain	0.183
Heifers Feed type = Rye	0.164
Heifers Feed type = Prairie	0.143
Heifers Feed type = Alfalfa	0.130
Heifers storage method = Land Applied	0.108
Heifers Feed type = Grass	0.106
Heifer feeding situation = Grazing Large Areas	0.099
Heifers Feed type = Grain	0.098
Heifers storage method = Anaerobic Digester with Biogas Utilization or Methane Cap...	0.091
Heifers solid treatment method = Deposited on Pasture/Range/Paddock	0.090
Heifers Seperator Type = Other	0.085
Heifers Liquid Treatment Method = Land Applied	0.082
Heifers Feed type = Sorghum	0.069
Heifers Liquid Treatment Method = Constructed wetland	0.069
Heifers storage method = Constructed wetland	0.067
Heifers solid treatment method = Temporary Stack and Long-Term Stockpile	0.067
Heifers Feed type = Orchardgrass	0.062
Heifers Feed type = Wheatgrass	0.061
Heifers Liquid Treatment Method = Thermochemical Conversion(Pyrolysis, Incinerati...	0.060
Heifers Feed type = Cheatgrass	0.058
Heifers solid treatment method = Thermochemical Conversion(Pyrolysis, Incineratio...	0.057
Heifers Seperator Type = Roller press	0.056
Heifers solid treatment method = Land Applied	0.056
Heifers Feed type = Elephant Grass	0.055
Heifers Feed type = Sanfoin	0.052
Heifers solid removed percentage	0.050
Heifers Seperator Type = Decanter centrifuge	0.048
Heifers Seperator Type = Stationary inclined screen	0.047
Heifers Liquid Treatment Method = Anaerobic Digester with Biogas Utilization or Met...	0.044
Heifers Feed type = Vetch	0.044
Heifers Feed type = Birdsfoot	0.042
Heifers storage method = Daily Spread	0.037
Heifers storage method = Thermochemical Conversion(Pyrolysis, Incineration, Gasifi...	0.037
Heifers storage method = Deposited on Pasture/Range/Paddock	0.035

Attribute	Weight
Heifers Feed type = Wheat	0.033
Heifers Seperator Type = Rotating screen	0.029
Heifers Liquid Treatment Method = Daily Spread	0.028
Heifers Feed type = Sudangrass	0.022
Heifer feeding situation = Pasture	0.022
Heifers Liquid Treatment Method = MISSING	0.020
Heifers solid treatment method = MISSING	0.020
Heifers Seperator Type = MISSING	0.020
Heifers Seperator Type = MISSING	0.020
Heifers Solid/Liquid seperator = Yes	0.020
Heifers Seperator Type = Vibrating screen	0.019
Heifers Liquid Treatment Method = Removed Offsite	0.016
Heifers Feed type = Meadow	0.015
Heifers storage method = Temporary Stack and Long-Term Stockpile	0.012
Heifers storage method = Composting	0.011
Heifers storage method = MISSING	0.009
Heifers solid treatment method = Removed Offsite	0.008
Heifers solid treatment method = Daily Spread	0.005
Heifers Seperator Type = Centrifuge	0.004
Heifers Feed type = Bromegrass	0.000

Fig. 4.90: COMET-Farm Stockers Attribute Weights

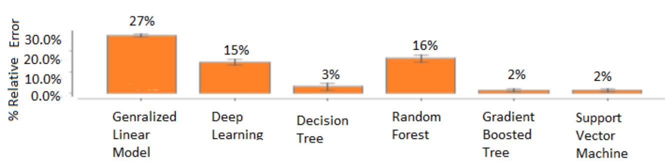


Fig. 4.91: COMET-Farm Feedlot Cattle Regression Models Relative error Overview

COMET-Farm Feedlot Cattle data consist of 91 attributes and we have trained models with around 1300 runs data. Figure 4.91 shoes relative errors for all six models we trained. Best model to generate data for Feedlot Cattle is Decision tree with 3% relative error and Gradient Boosted Tree and Support Vector Machine with 2% relative error. Predictions Chart for Generalized Linear Model is shown in Figure 4.92. This model got trained with a relative error of 27%. We can see in the figure that there are many outliers. Figure 4.93 shows Predictions Chart for Deep Learning Method, many predicted values got deflected from actual value line. This model gives relative error of 15%. Similarly, Figure 4.95 shows

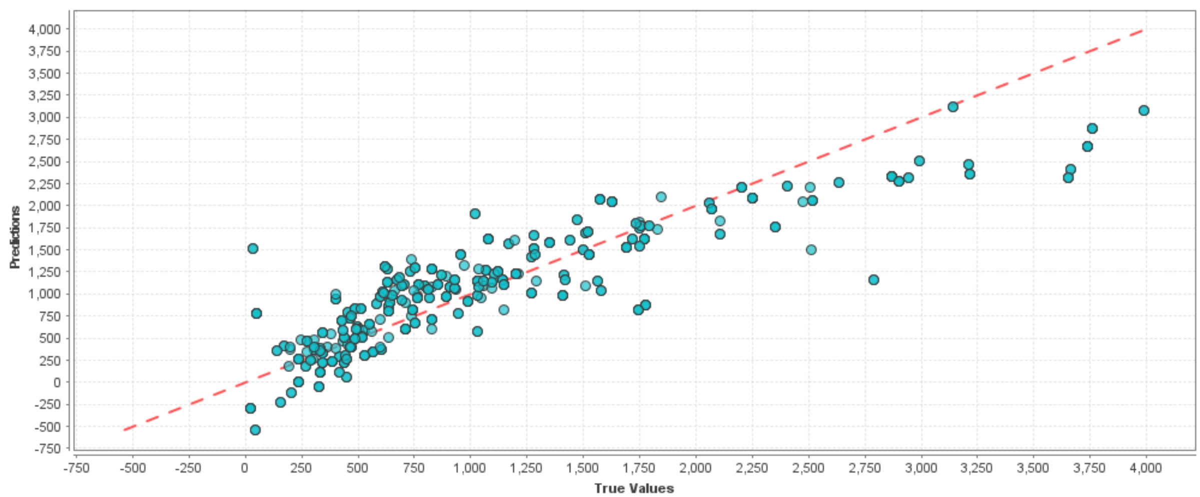


Fig. 4.92: COMET-Farm Feedlot Cattle Crop Generalized Linear Model Predictions Chart

Predictions Chart for Random Forest Method with 16% relative error.

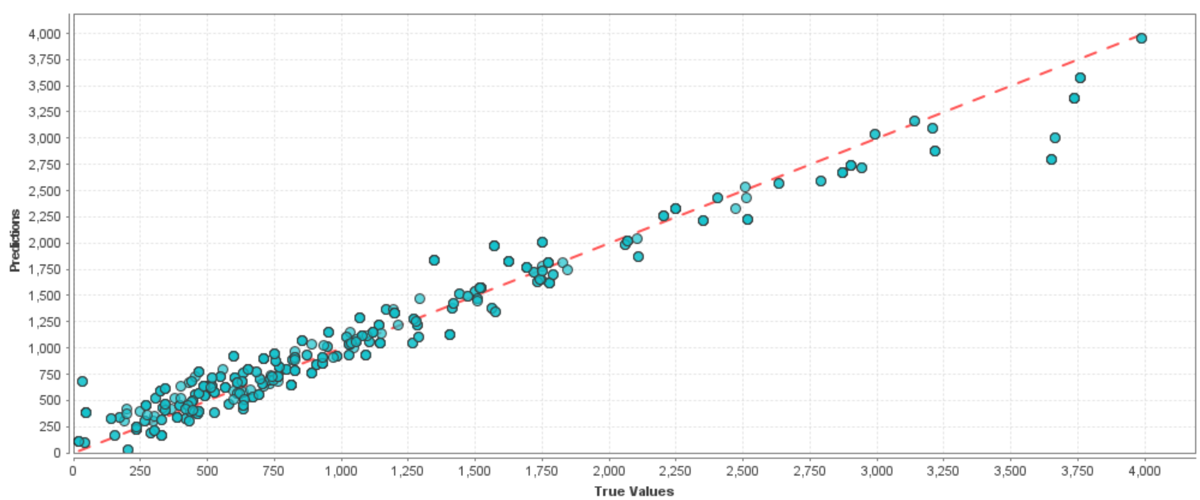


Fig. 4.93: COMET-Farm Feedlot Cattle Deep Learning Predictions Chart

Decision Tree Model predicted values with 3% relative error. Predictions Chart for Decision Tree Model is shown in Figure 4.94. Decision Tree also generates a Decision Tree which is shown in Figure 4.99. This tree is further shown in different parts in Figure 4.100, Figure 4.101, Figure 4.102, Figure 4.103, Figure 4.104, and Figure 4.105.

Gradient Boosted Tree Predictions Chart is shown in Figure 4.96. This model gives relative error 2%. Gradient Boosted Model also generates 100's of trees which shows at-

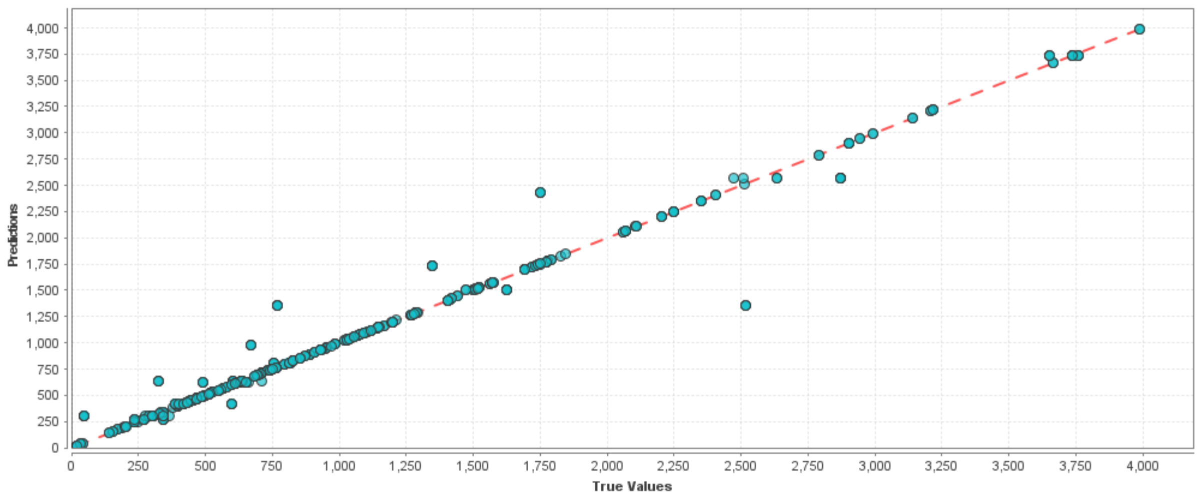


Fig. 4.94: COMET-Farm Feedlot Cattle Decision Tree Predictions Chart

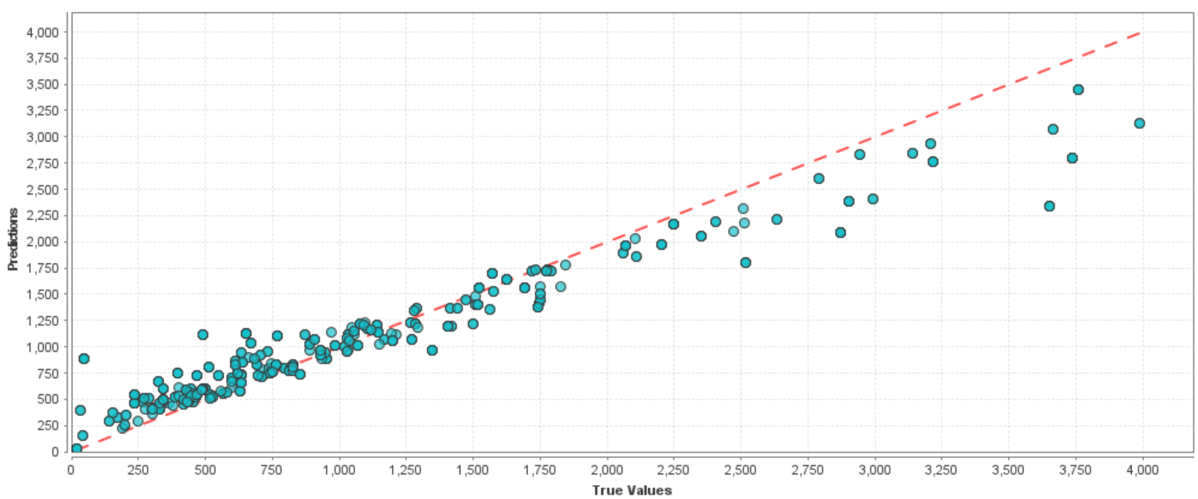


Fig. 4.95: COMET-Farm Feedlot Cattle Random Forest Predictions Chart

tribute dependency on result. One of the trees is shown in Figure 4.98. Support Vector Machine model also gives relative error of 2%, its Predictions Chart is shown in Figure 4.97.

Attributes Weights are shown in Figure 4.106. This attribute is calculated by RapidMiner by using all the models data. From this figure we can determine which attribute is affecting the GHG emissions by what weight. In this figure we can see Heifers and Steers count is affecting the GHG emission most. Solid Treatment method Compositing and Liquid Treatment method Aerobic Lagoon has high impact on the result. an Farmers can choose the Management activities with less weight for low GHG emissions.

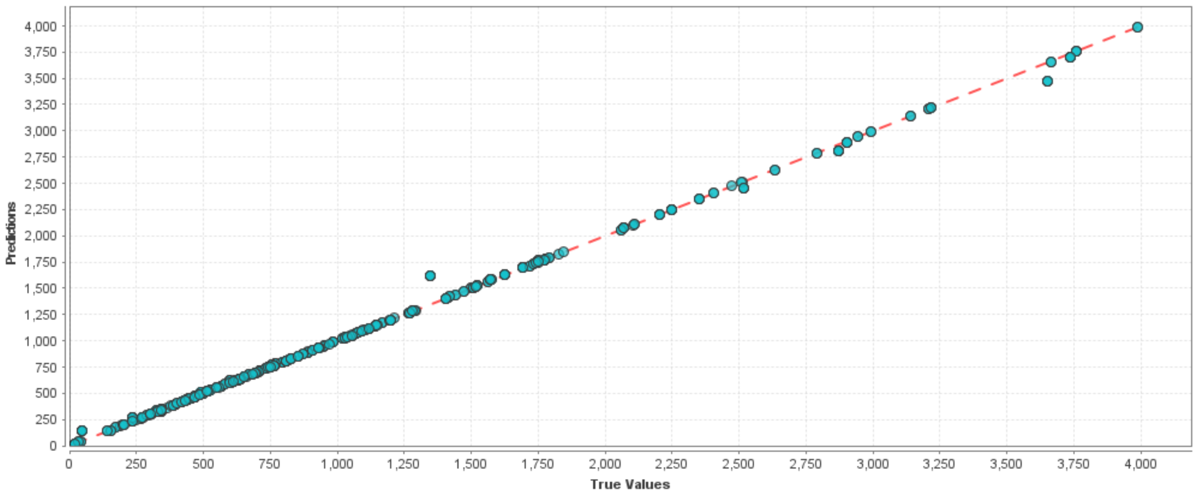


Fig. 4.96: COMET-Farm Feedlot Cattle Gradient Boosted Tree Predictions Chart

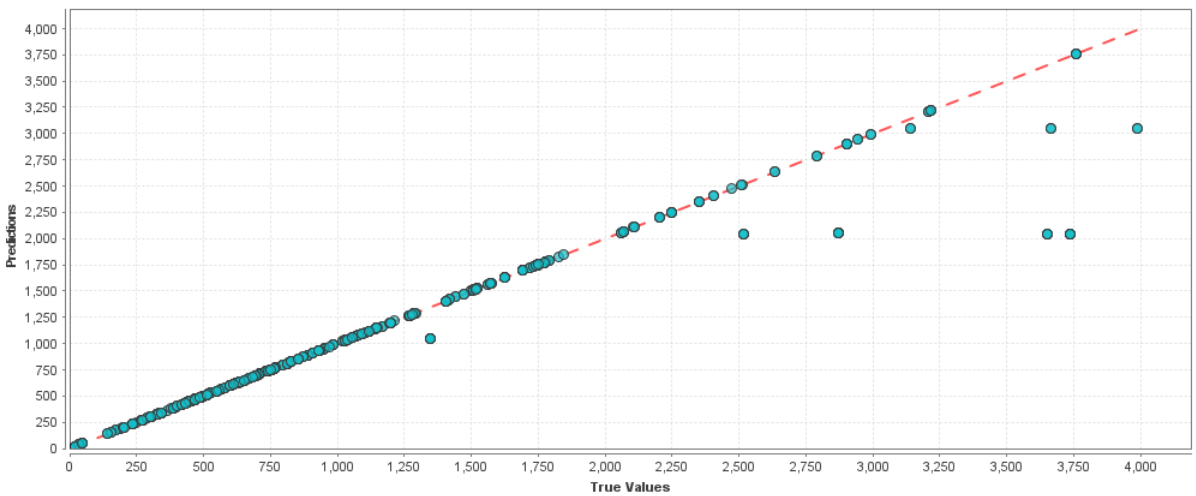


Fig. 4.97: COMET-Farm Feedlot Cattle Support Vector Machine Predictions Chart

Fig. 4.98: COMET-Farm Feedlot Cattle Gradient Boosted Tree

Fig. 4.99: COMET-Farm Feedlot Cattle Decision Tree

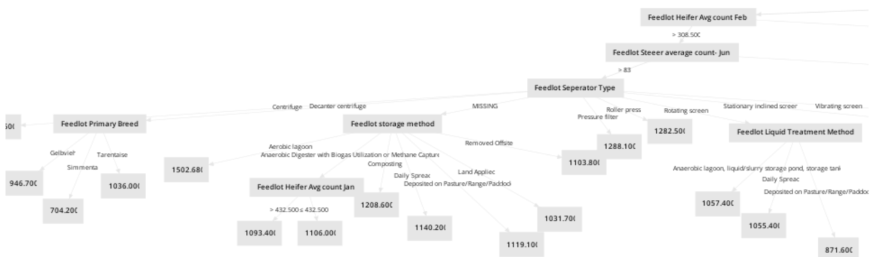


Fig. 4.100: COMET-Farm Feedlot Cattle Decision Tree Part 1

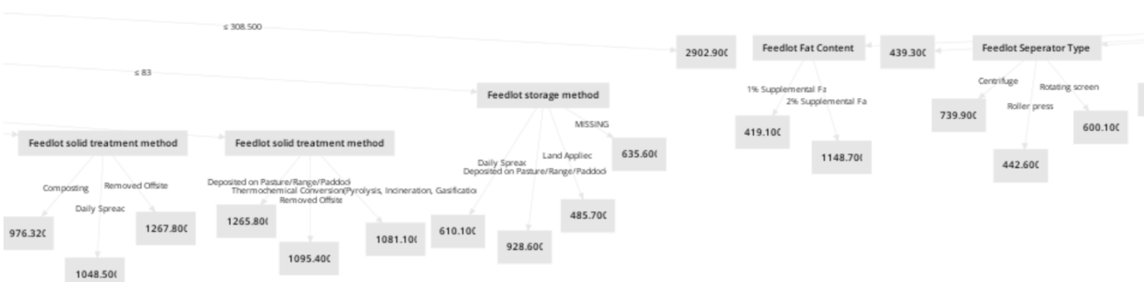


Fig. 4.101: COMET-Farm Feedlot Cattle Decision Tree Part 2

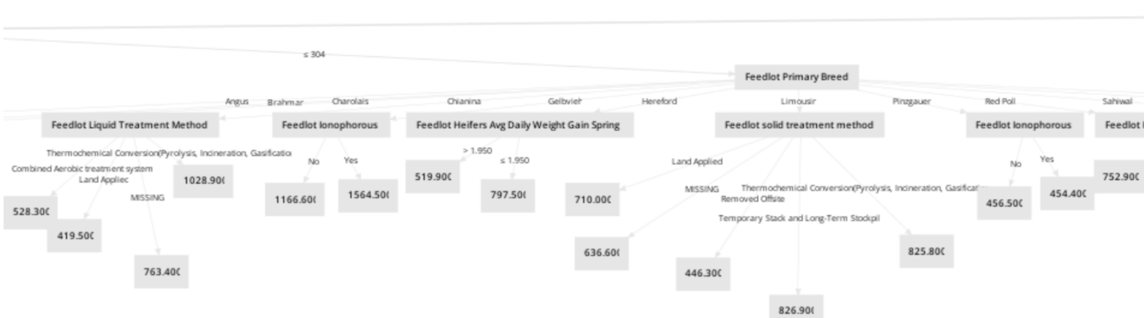


Fig. 4.102: COMET-Farm Feedlot Cattle Decision Tree Part 3

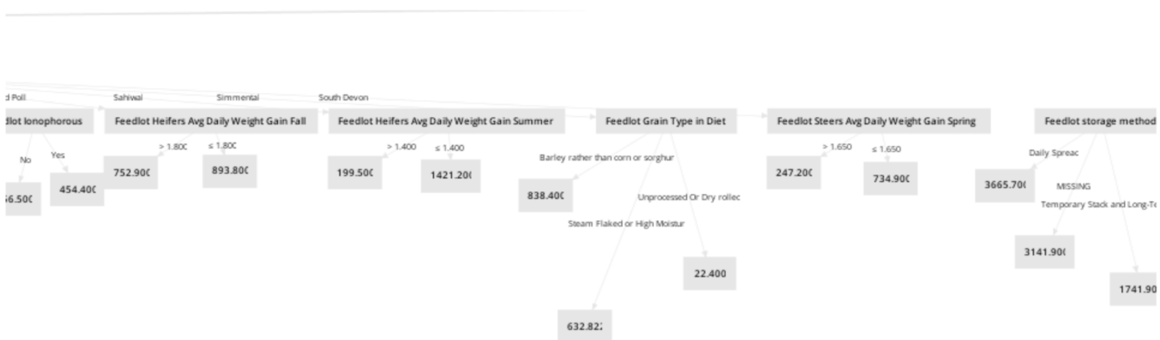


Fig. 4.103: COMET-Farm Feedlot Cattle Decision Tree Part 4

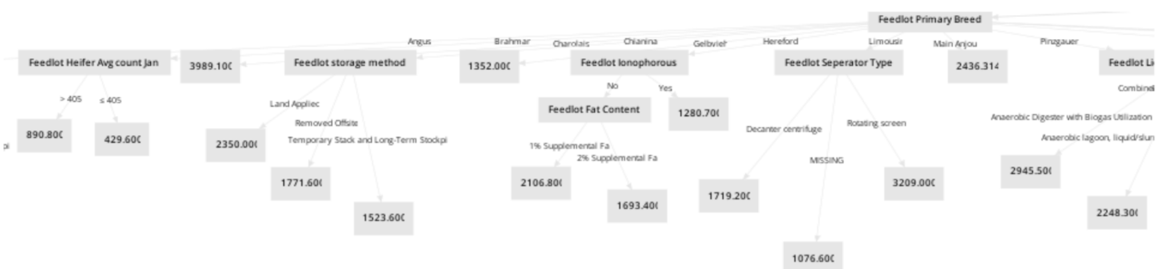


Fig. 4.104: COMET-Farm Feedlot Cattle Decision Tree Part 5

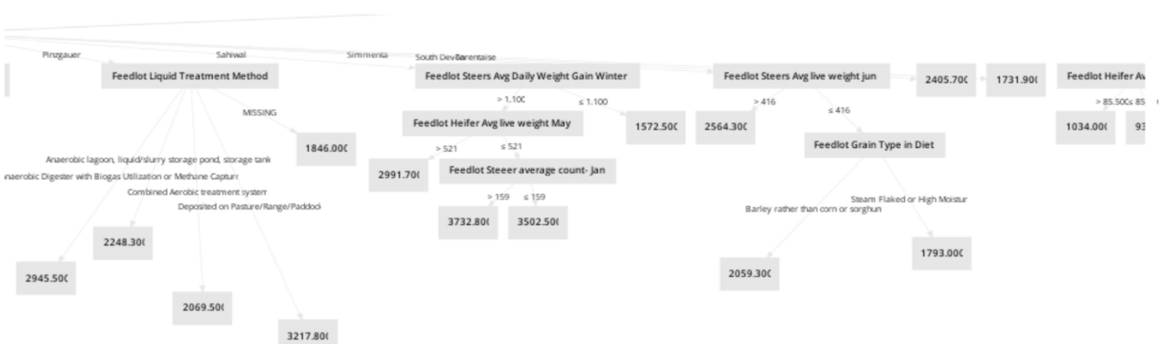


Fig. 4.105: COMET-Farm Feedlot Cattle Decision Tree Part 6

COMET-Farm Dairy-Lactating Cows datset is of size 1000. It has 67 different attributes. Figure 4.107 shows relative error for all six models we have used to train with out dataset.

For Generalized Linear Model Predictions Chart is shown in Figure 4.108. Generalized

Attribute	Weight
Feedlot Heifer Avg count Oct	0.403
Feedlot Heifer Avg count Dec	0.402
Feedlot Heifer Avg count Sep	0.402
Feedlot Heifer Avg count May	0.401
Feedlot Heifer Avg count Apr	0.401
Feedlot Heifer Avg count Nov	0.401
Feedlot Heifer Avg count Jun	0.400
Feedlot Heifer Avg count Mar	0.400
Feedlot Heifer Avg count Jul	0.400
Feedlot Heifer Avg count Aug	0.400
Feedlot Heifer Avg count Feb	0.399
Feedlot Heifer Avg count Jan	0.398
Feedlot Concentrate Percentage in Diet = More than 60 percent grain	0.390
Feedlot Steeer average count- Mar	0.255
Feedlot Steeer averagecount- Oct	0.255
Feedlot Steeer average count- Jul	0.255
Feedlot Steeer average count- Nov	0.254
Feedlot Steeer average count- Dec	0.254
Feedlot Steeer average count- Aug	0.253
Feedlot Steeer average count- Sep	0.253
Feedlot Steeer average count- Feb	0.253
Feedlot Steeer average count- Jun	0.252
Feedlot Primary Breed = Sahiwal	0.252
Feedlot Steeer average count- Apr	0.251
Feedlot Steeer average count- Jan	0.251
Feedlot Steeer average count- May	0.248
Feedlot solid treatment method = Composting	0.233
Feedlot Liquid Treatment Method = Aerobic lagoon	0.194
Feedlot Fat Content = 2% Supplemental Fat	0.175
Feedlot Fat Content = 1% Supplemental Fat	0.148
Feedlot storage method = Constructed wetland	0.139
Feedlot Primary Breed = Brahman	0.131
Feedlot Seperator Type = Vibrating screen	0.122
Feedlot Liquid Treatment Method = Anaerobic lagoon, liquid/slurry storage pond, stor...	0.122
Feedlot Liquid Treatment Method = Daily Spread	0.121
Feedlot Primary Breed = Pinzgauer	0.119
Feedlot Seperator Type = Centrifuge	0.119
Feedlot storage method = Land Applied	0.117
Feedlot solid treatment method = Temporary Stack and Long-Term Stockpile	0.117
Feedlot Liquid Treatment Method = Removed Offsite	0.113
Feedlot storage method = Daily Spread	0.108
Feedlot solid treatment method = Thermochemical Conversion(Pyrolysis, Incineratio...	0.095
Feedlot solid treatment method = Deposited on Pasture/Range/Paddock	0.090
Feedlot Steers Avg Daily Weight Gain Winter	0.087
Feedlot Steers Avg Daily Weight Gain Summer	0.086
Feedlot Primary Breed = Chianina	0.086
Feedlot Heifers Avg Daily Weight Gain Winter	0.086

Attribute	Weight
Feedlot Seperator Type = Stationary inclined screen	0.084
Feedlot solid removed percentage	0.084
Feedlot Liquid Treatment Method = Land Applied	0.081
Feedlot Liquid Treatment Method = Thermochemical Conversion(Pyrolysis, Incinerati...	0.078
Feedlot Heifer Avg live weight Oct	0.072
Feedlot Primary Breed = Red Poll	0.070
Feedlot Heifer Avg live weight Apr	0.070
Feedlot Heifer Avg live weight Nov	0.066
Feedlot Heifer Avg live weight Sep	0.065
Feedlot Heifer Avg live weight Dec	0.064
Feedlot Liquid Treatment Method = Constructed wetland	0.063
Feedlot Heifer Avg live weight May	0.063
Feedlot Heifer Avg live weight Mar	0.062
Feedlot Heifer Avg live weight Aug	0.062
Feedlot Heifer Avg live weight Jan	0.060
Feedlot Heifer Avg live weight Jun	0.059
Feedlot Steers Avg live weight Dec	0.058
Feedlot Heifer Avg live weight Jul	0.058
Feedlot storage method = Deposited on Pasture/Range/Paddock	0.057
Feedlot Heifer Avg live weight Feb	0.056
Feedlot Steers Avg live weight Nov	0.056
Feedlot Steers Avg live weight Oct	0.056
Feedlot storage method = Thermochemical Conversion(Pyrolysis, Incineration, Gasifi...	0.053
Feedlot storage method = Composting	0.049
Feedlot Primary Breed = Charolais	0.049
Feedlot Steers Avg live weight may	0.047
Feedlot Primary Breed = Gelbvieh	0.046
Feedlot Seperator Type = Rotating screen	0.045
Feedlot Steers Avg Daily Weight Gain Spring	0.044
Feedlot Steers Avg live weight Mar	0.043
Feedlot Steers Avg live weight feb	0.043
Feedlot Steers Avg live weight aug	0.042
Feedlot Steers Avg live weight jun	0.040
Feedlot Steers Avg live weight Sep	0.039
Feedlot storage method = Temporary Stack and Long-Term Stockpile	0.039
Feedlot Steers Avg live weight Jul	0.037
Feedlot Steers Avg live weight Apr	0.037
Feedlot solid treatment method = Land Applied	0.036
Feedlot Primary Breed = Tarentaise	0.035
Feedlot Steers Avg live weightJan	0.032
Feedlot Grain Type in Diet = Steam Flaked or High Moisture	0.030
Feedlot Primary Breed = Hereford	0.029
Feedlot Ionophorous = No	0.029
Feedlot Primary Breed = Limousin	0.028
Feedlot Heifers Avg Daily Weight Gain Summer	0.028
Feedlot Primary Breed = Angus	0.028
Feedlot storage method = Removed Offsite	0.026

Attribute	Weight
Feedlot Heifers Avg Daily Weight Gain Fall	0.020
Feedlot Heifers Avg Daily Weight Gain Spring	0.018
Feedlot Solid/Liquid seperator = No	0.017
Feedlot storage method = MISSING	0.017
Feedlot Liquid Treatment Method = Deposited on Pasture/Range/Paddock	0.014
Feedlot Seperator Type = Decanter centrifuge	0.013
Feedlot Liquid Treatment Method = Combined Aerobic treatment system	0.012
Feedlot Primary Breed = Main Anjou	0.009
Feedlot Ionophorous = Yes	0.007
Feedlot solid treatment method = Removed Offsite	0.006
Feedlot Solid/Liquid seperator = Yes	0.005
Feedlot Liquid Treatment Method = MISSING	0.005
Feedlot solid treatment method = MISSING	0.005
Feedlot Seperator Type = MISSING	0.005
Feedlot Seperator Type = Roller press	0.003
Feedlot Grain Type in Diet = Unprocessed Or Dry rolled	0.002

Fig. 4.106: COMET-Farm Feedlot Cattle Attribute Weights

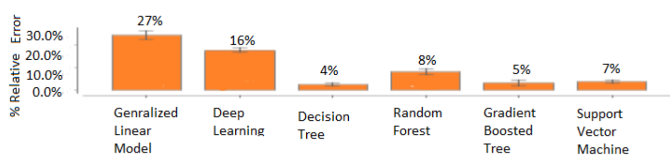


Fig. 4.107: COMET-Farm Dairy-Lactating Cow Regression Models Relative error Overview

linear model is predicting the values with 27% relative error. We can see in this figure that there are deflected values from actual value line. Figure 4.109 shows Predictions Chart for Deep Learning Model. Relative error for this model is 16%. Random Forest Predictions Chart is shown in Figure 4.111.

Gradient Boosted Tree model predicted the values with 5% relative error. Its Predictions Chart is shown in Figure 4.112 we can see in this figure there are a few outliers present in it. Gradient Boosted Tree model generates different Gradient Boosted Tree one of which is shown in Figure 4.114. In Figure 4.113 Predictions Chart for Support Vector Machine model is shown with relative error of 7%. Decision Tree Predictions Chart is shown in Figure 4.110.

Decision Tree model is predicting values for Diary-Lactating Cows dataset with 4%.

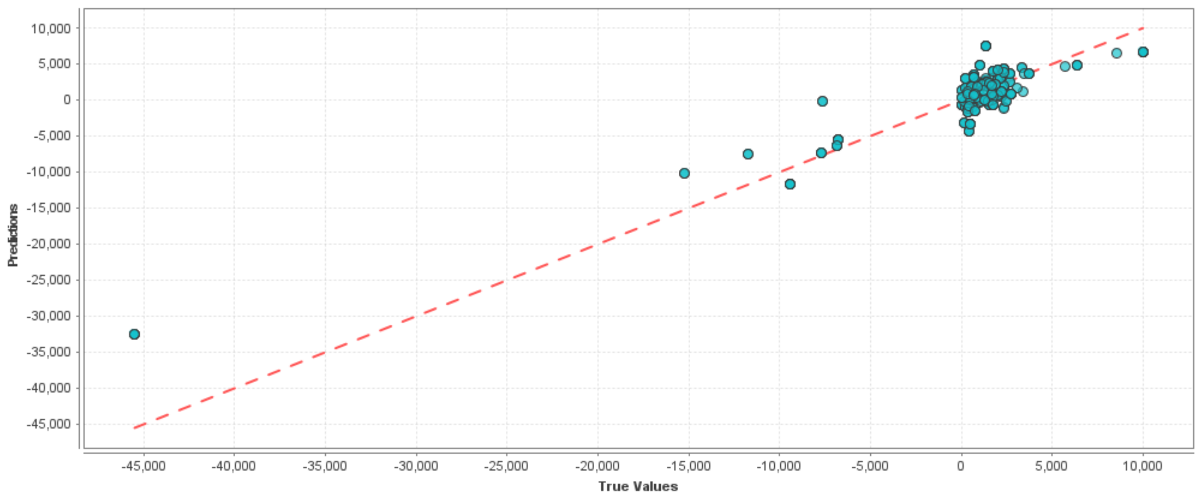


Fig. 4.108: COMET-Farm Dairy-Lactating Cow Crop Generalized Linear Model Predictions Chart

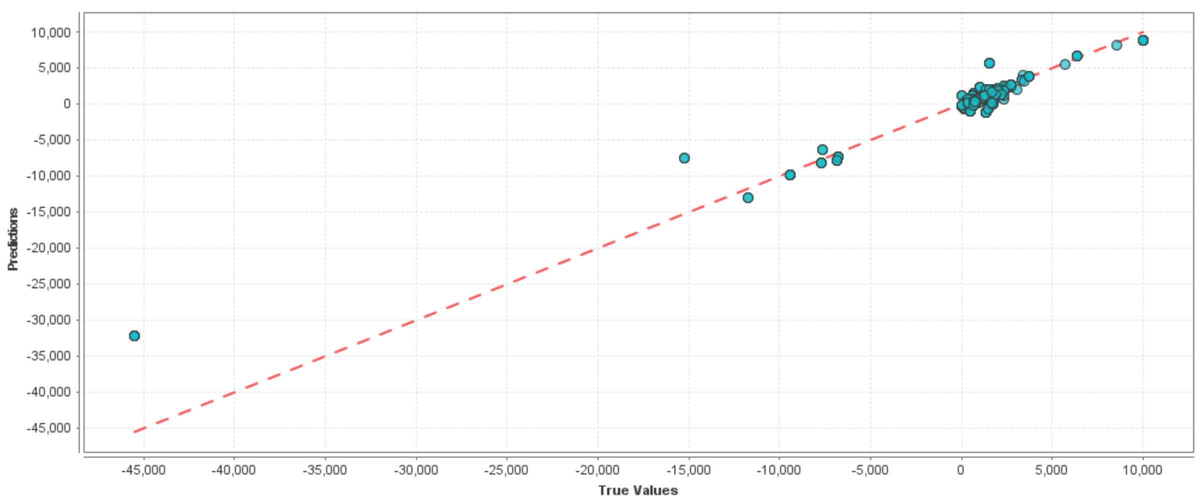


Fig. 4.109: COMET-Farm Dairy-Lactating Cow Deep Learning Predictions Chart

This model also generates a Decision Tree which is shown in Figure 4.115. This tree shows relationship between the attributes and also how they are impacting the result. This a big tree as we have 67 attributes present in it, So we further divided tree into Figure 4.116, Figure 4.117, Figure 4.118, Figure 4.119, and Figure 4.120. As we can see in Figure 4.116 if our Roofed Facility Count is less than or equal to 382 then Liquid Treatment Method Land Applied will give less GHG emission than other methods. And in Figure 4.117 it shows how separator type is affecting result. Attribute Weights by which they are affecting the result

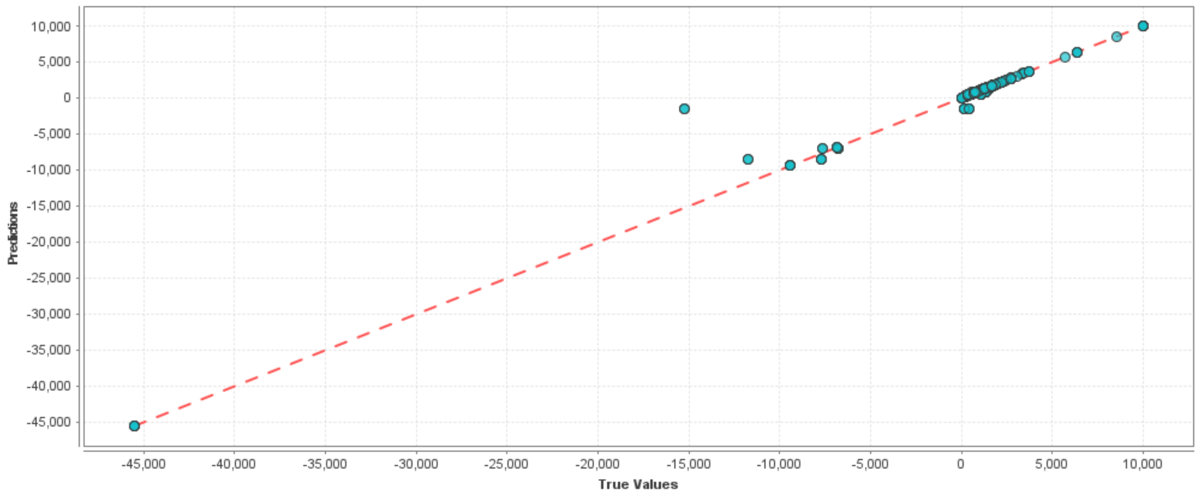


Fig. 4.110: COMET-Farm Dairy-Lactating Cow Decision Tree Predictions Chart

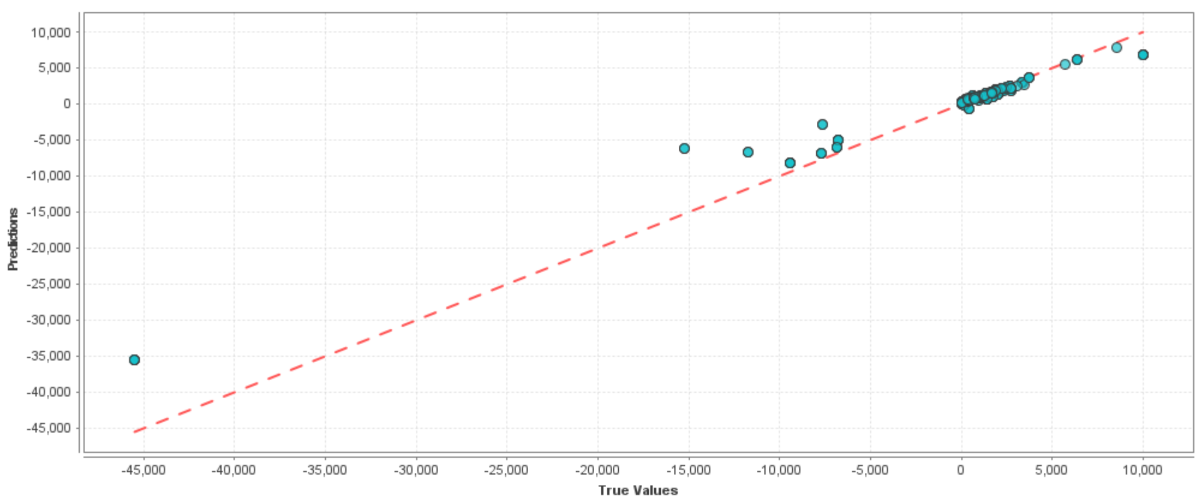


Fig. 4.111: COMET-Farm Dairy-Lactating Cow Random Forest Predictions Chart

is shown in Figure 4.106. In this figure we can conclude that Feed type Wheat is affecting the GHG emission. Also Bedding method Pit Storage days in pit has high impact.

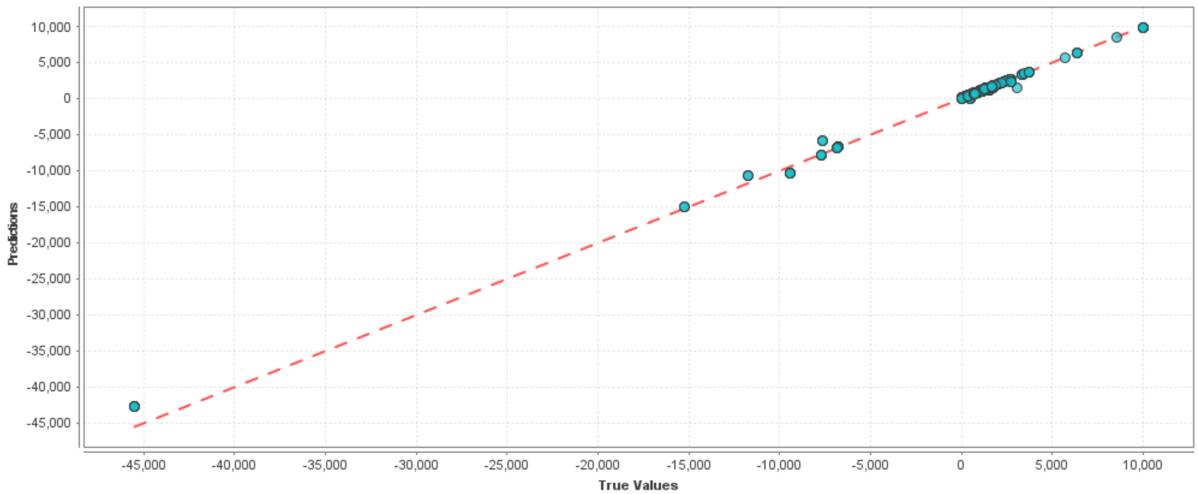


Fig. 4.112: COMET-Farm Dairy-Lactating Cow Gradient Boosted Tree Predictions Chart

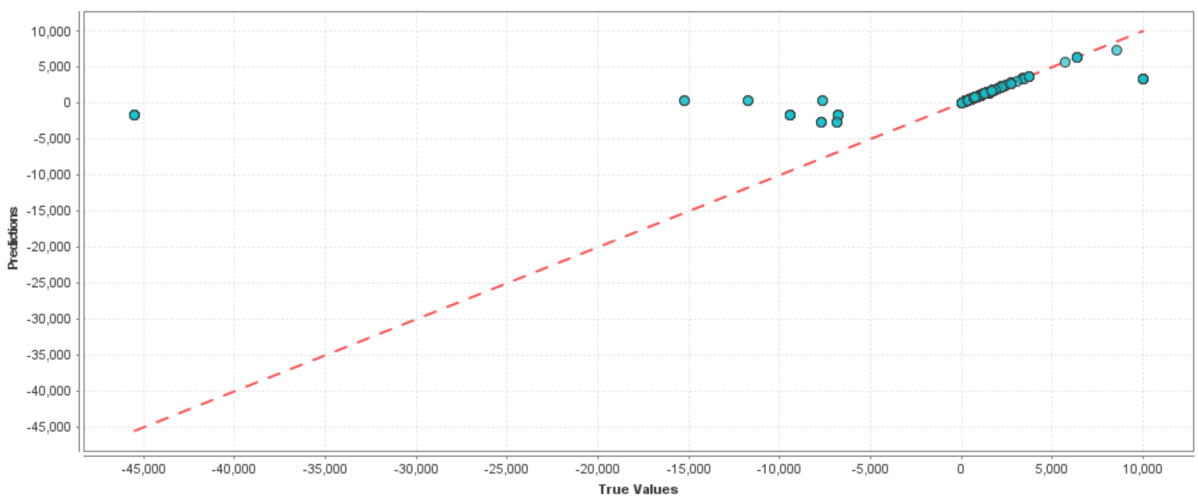


Fig. 4.113: COMET-Farm Dairy-Lactating Cow Support Vector Machine Predictions Chart

Fig. 4.114: COMET-Farm Dairy-Lactating Cow Gradient Boosted Tree

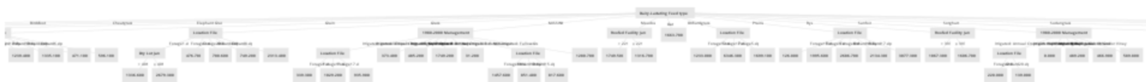


Fig. 4.115: COMET-Farm Dairy-Lactating Cow Decision Tree

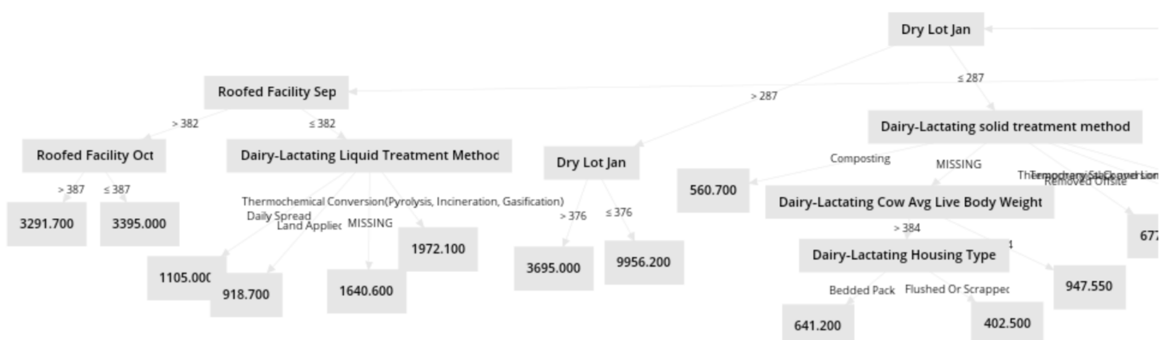


Fig. 4.116: COMET-Farm Dairy-Lactating Cow Decision Tree Part 1

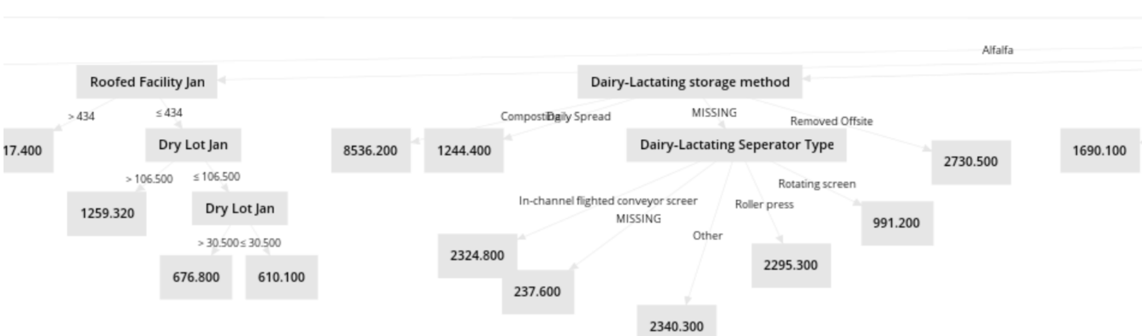


Fig. 4.117: COMET-Farm Dairy-Lactating Cow Decision Tree Part 2

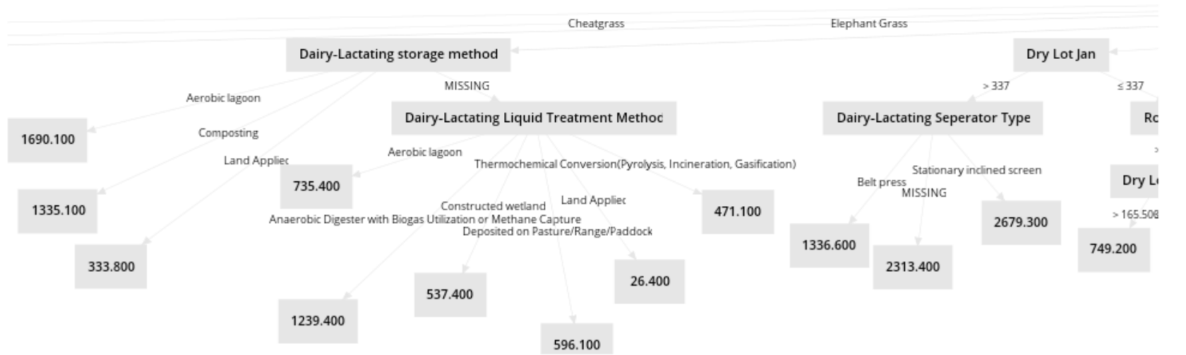


Fig. 4.118: COMET-Farm Dairy-Lactating Cow Decision Tree Part 3

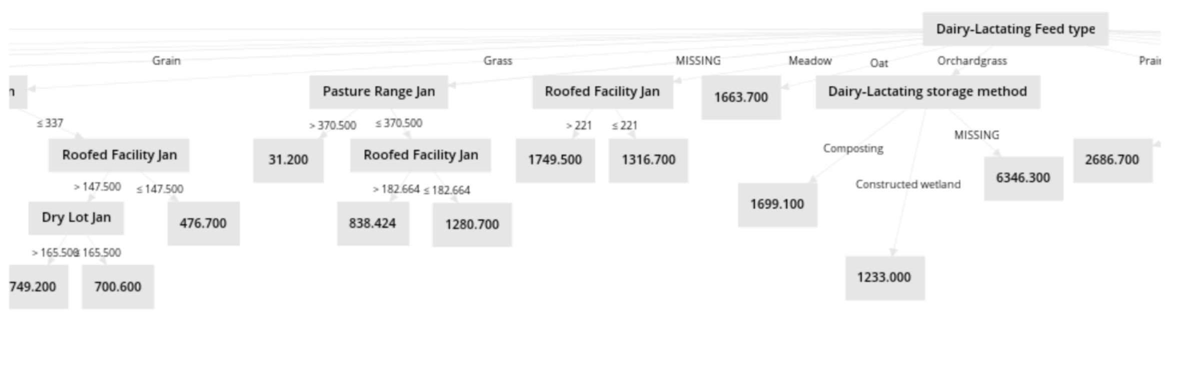


Fig. 4.119: COMET-Farm Dairy-Lactating Cow Decision Tree Part 4

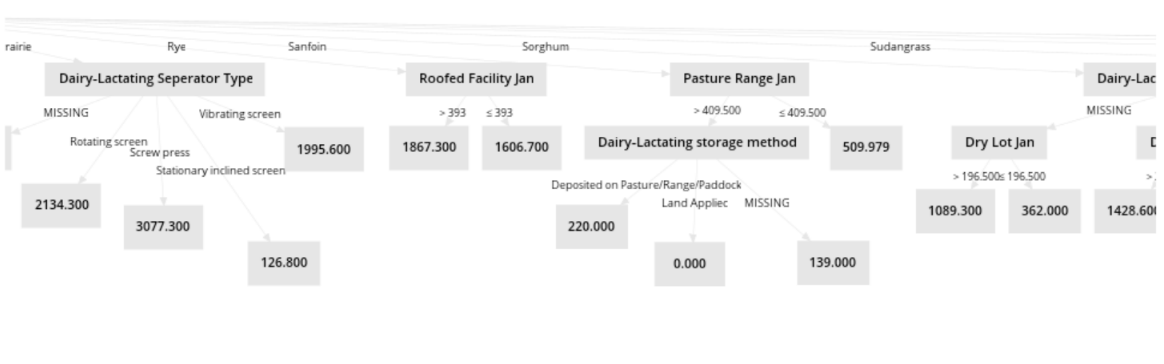


Fig. 4.120: COMET-Farm Dairy-Lactating Cow Decision Tree Part 5

Attribute	Weight
Dairy-Lactating Feed type = Wheat	0.569
Dairy-Lactating storage method = Removed Offsite	0.459
Location File = Forage2.zip	0.375
Dairy-Lactating Pit Storage days in housing	0.242
1980-2000 Management = Non-Irrigated: Orchard or Vineyard	0.224
Dairy-Lactating Feed type = Sorghum	0.219
Dairy-Lactating storage method = Composting	0.160
Dairy-Lactating Cow Avg Live Body Weight	0.145
1980-2000 Tillage Inensity = Intensive Tillage	0.137
Dairy-Lactating Housing Type = Pit Storage	0.134
Dairy-Lactating Pit Storage Type = MISSING	0.129
Type of crop = Annual crop	0.126
Location File = Orchard8.zip	0.121
Dairy-Lactating Pit Storage Type = Deep	0.116
Location File = Forage6.zip	0.116
1980-2000 Management = Irrigated: Annual Crops in Rotation	0.114
Dairy-Lactating Feed type = Elephant Grass	0.112
Dry Lot Jan	0.103
Type of crop = Seasonal crop cover	0.096
Dry Lot Dec	0.095
Dry Lot Feb	0.095
Dry Lot May	0.093
Dry Lot Apr	0.093
Dry Lot Jul	0.092
Dry Lot Nov	0.091
Dry Lot Jun	0.091
Dry Lot Mar	0.090
Dairy-Lactating solid treatment method = Daily Spread	0.090
Dairy-Lactating Feed type = Wheatgrass	0.089
Dry Lot Oct	0.088
Dry Lot aug	0.088
Dairy-Lactating Feed type = Orchardgrass	0.087
Dairy-Lactating Liquid Treatment Method = Deposited on Pasture/Range/Paddock	0.086
Dairy-Lactating Feed type = Birdsfoot	0.086
Dry Lot Sep	0.085
Roofed Facility Sep	0.083
Roofed Facility Jan	0.081
Roofed Facility Nov	0.081
Roofed Facility Oct	0.080
1980-2000 Management = Non-Irrigated: Fallow-Grain	0.079
Location File = Forage16.zip	0.079
Roofed Facility Aug	0.079
Roofed Facility Dec	0.078
Roofed Facility Feb	0.078
Roofed Facility Mar	0.077
Location File = Forage17.zip	0.076
Dairy-Lactating Seperator Type = In-channel flighted conveyor screen	0.076
Roofed Facility Apr	0.076

Attribute	Weight
Dairy-Lactating Housing Type = Flushed Or Scrapped	0.076
Roofed Facility Jul	0.074
Roofed Facility May	0.073
Dairy-Lactating storage method = Temporary Stack and Long-Term Stockpile	0.073
Dairy-Lactating Feed type = Alfalfa	0.072
Location File = Forage18.zip	0.071
Pasture Range Jun	0.071
1980-2000 Management = Non-Irrigated: Continuous Hay	0.071
Pasture Range Mar	0.071
Roofed Facility Jun	0.069
Dairy-Lactating solid treatment method = Land Applied	0.069
Location File = Orchard7.zip	0.069
Dairy-Lactating storage method = MISSING	0.069
Dairy-Lactating Solid/Liquid seperator = No	0.069
Pasture Range Apr	0.069
Pre-1980 Management = Lowland Non-Irrigated (Pre 1980s)	0.068
Location File = Forage1.zip	0.066
Pasture Range feb	0.065
1980-2000 Management = Irrigated: Annual Crops with Hay/Pasture in Rotation	0.064
Pasture Range Jul	0.064
Pasture Range May	0.064
Pre-1980 Management = Livestock Grazing	0.062
Pasture Range Aug	0.061
Dairy-Lactating Solid/Liquid seperator = Yes	0.060
1980-2000 Tillage Inensity = Reduced Tillage	0.060
Pasture Range Nov	0.059
Dairy-Lactating Liquid Treatment Method = MISSING	0.058
Dairy-Lactating solid treatment method = MISSING	0.058
Dairy-Lactating Seperator Type = MISSING	0.058
1980-2000 Management = Irrigated: Continuous Hay	0.058
Pasture Range Jan	0.057
Dairy-Lactating Bedded Pack Type = No Mix	0.057
Dairy-Lactating solid treatment method = Deposited on Pasture/Range/Paddock	0.056
Dairy-Lactating Feed type = Vetch	0.056
Dairy-Lactating Liquid Treatment Method = Daily Spread	0.056
Pasture Range Dec	0.055
Dairy-Lactating Housing Type = Bedded Pack	0.054
Location File = Forage12.zip	0.054
Dairy-Lactating Bedde days in housing	0.054
Location File = Forage5.zip	0.053
Dairy-Lactating Seperator Type = Rotating screen	0.053
Dairy-Lactating Feed type = Prairie	0.052
Location File = Forage10.zip	0.051
Dairy-Lactating Liquid Treatment Method = Aerobic lagoon	0.046
Dairy-Lactating Liquid Treatment Method = Anaerobic Digester with Biogas Utilizatio...	0.043
Pre-1980 Management = Upland Non-Irrigated (Pre 1980s)	0.040
Location File = Forage14.zip	0.037
1980-2000 Management = Non-Irrigated: Annual Crops in Rotation	0.036
Dairy-Lactating Seperator Type = Screw press	0.035

Attribute	Weight
Location File = Orchard18.zip	0.034
Dairy-Lactating storage method = Daily Spread	0.033
Dairy-Lactating Feed type = Rye	0.032
Dairy-Lactating Feed type = Grass	0.032
Location File = Orchard5.zip	0.025
Dairy-Lactating solid treatment method = Composting	0.025
Location File = Forage19.zip	0.025
Dairy-Lactating storage method = Constructed wetland	0.024
Dairy-Lactating Seperator Type = Other	0.023
Location File = Orchard20.zip	0.023
Dairy-Lactating storage method = Land Applied	0.022
Dairy-Lactating Liquid Treatment Method = Thermochemical Conversion(Pyrolysis, I...	0.021

Fig. 4.121: COMET-Farm Dairy-Lactating Cow Attribute Weights

CHAPTER 5

Conclusion and Future Work

This thesis consists of three parts. First, we automated Whole-Farm Carbon Model applications. It was important to automate the models since we wanted to run the applications for thousands of farm scenarios. We chose to automate HOLOS, which is a desktop application, and COMET-Farm, which is a web application. We automated HOLOS using WinAppDriver in python and COMET-Farm web application using Selenium with Python. We automated these applications to collect data on GHG emissions of the farms based on crop and animal inputs. Second, we collected data from running the applications. Each run paired input to output of estimates of GHGs. We randomly generated the inputs, the farm scenarios, but used expert advice to limit the scenarios to those that calibrate to real-world scenarios. Third, and finally, we used RapidMiner to train different Regression models on the runs of the applications. We achieved high accuracy with the trained models.

By training the Regression models we were able to determine which input attributes had the greatest impact. This knowledge helps farm managers rank management practices. We also generated decision trees, which visualize, for farm managers, the practices which yield the greatest benefit for GHG emissions.

In the future, we plan to extend our automation to other Whole-Farm Carbon models, such as IFSM, LUCI, and INVEST. Our ultimate goal is to build a hybrid model to incorporate different features of all these applications. Each model covers a slightly different scenario, and no unifying model exists. But by data mining the individual models, we can construct a hybrid model that integrates the disparate GHG emissions estimates and provides a single resource for farm managers.

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